EVALUATION OF SAFETY IMPROVEMENTS AT HIGHWAY-RAILWAY GRADE CROSSINGS

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BY

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JHRP

JOINT HIGHWAY RESEARCH PROJECT
PURDUE UNIVERSITY AND
INDIANA STATE HIGHWAY COMMISSION

Interim Report

EVALUATION OF SAFETY IMPROVEMENTS AT HIGHWAY-RAILWAY GRADE CROSSINGS

TO: J. F. McLaughlin, Director
Joint Highway Research Project

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

February 8, 1973

Project: C-36-59N

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The attached Interim Report is submitted on the HPR Part II Research Study titled "A Field Evaluation of Driver Information Systems for Highway Railway Grade Crossings". The Report is titled "Evaluation of Safety Improvements at Highway-Railway Grade Crossings" and has been authored by Thomas A. Butcher, Graduate Assistant in Research on our staff. Professor H. L. Michael served as director of the research.

This Report concerns an evaluation of the speed profiles of drivers approaching the US 31-N&W Railroad crossing near Tipton, Indiana with standard flashing light signals in place. Speed profiles under conditions of non-actuation and several conditions of actuation are analyzed. The several phases of additional protection which were to be added to this crossing and evaluated have not as yet been added because of inability to date of the ISHC and the Railroad to prepare a satisfactory agreement. Evaluation of the additional items of protection is planned if and when installed.

The Report also includes a thorough review of innovative protection devices at railroad crossings which have been tried or proposed. One of those which is in place at a number of crossings in Indiana, the Monon green light, was evaluated by field observations and is reported in some detail.

The Report is submitted as partial fulfillment of the objectives of this Study. It will be similarly submitted to the ISHC and FHWA for their review, comment and acceptance.

Respectfully submitted,

Harold L Michael

Harold L. Michael, Associate Director

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16. Abstract

In recognition that added effort must be placed on reducing the conflict at highway-railroad grade crossings, this research to evaluate means of supplying motorists with more credible and forceful information was developed. Many innovative active protection devices for grade crossings have been tried or proposed. Many such devices are reviewed with evaluations of their effectiveness, if any were available. The "Monon green light" signal, several of which are in Indiana, was field observed for effectiveness and recommendations are made for improvements.

A study of speed profiles of vehicles approaching a crossing protected by a standard flashing light system is also reported. A photographic data collection system was developed which allowed determination of vehicle speed profiles, thus indicating driver reaction to the crossing condition. Speed profiles for non-actuated and actuated signal conditions are analyzed. It was determined that drivers approaching the crossing under progressively greater stimulus relative to an approaching train entered the approach at correspondingly slower speeds.

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The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein.. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Purdue University
West Lafayette, Indiana
February 8, 1972

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ABSTRACT

Butcher, Thomas Allan. M.S.C.E., Purdue University, December 1972. EVALUATION OF SAFETY IMPROVEMENTS AT HIGHWAY-RAILWAY GRADE CROSSINGS. Major Professor: Harold L. Michael.

Highway-railway grade crossing accidents claim a disproportionate number of lives each year on the nation's roads. Grade separation structures for every crossing would eliminate this conflict, but at a totally unrealistic cost. Therefore, efforts must be focused toward reducing the conflict by supplying the motorist with the most credible and forceful information possible concerning his responsibility at the crossing.

In the past, innovative active protection devices for the crossing have been proposed and developed with the view toward providing increased safety at a fraction of the cost of upgrading standard devices (e.g., from crossbucks to standard flashing light signals). Several such devices are reviewed, including an evaluation of the effectiveness of each, when possible. The existing need for innovations in crossing protection is also examined. It is recommended that inter-agency relations must be improved to facilitate development and testing of innovative devices and to allow for more widespread application of devices which prove to be effective.

A study was initiated by which innovative devices may be evaluated over a relatively short period of time. A photographic data collection system was developed which allowed the determination of speed profiles of vehicles approaching a grade crossing, thus indicating driver reaction to the prevailing crossing conditions. Using this system, data were collected at a particularly hazardous rural crossing in Indiana which is protected by standard flashing light signals. It was found that actions of groups of motorists in several categories (which were based upon prevailing crossing conditions) could not be distinguished on the basis of deceleration rates, thus indicating that drivers involved in grade crossing accidents are singularly inattentive or distracted. It was also determined that drivers approaching the crossing under progressively greater stimulus as to the hazard involved entered the approach at correspondingly slower speeds and decelerated more gradually.

It is recommended that similar data be collected after each of several additions are made to the crossing protection at this site in order to identify those which have the greatest positive impact on driver performance.

CHAPTER I. INTRODUCTION

Railroad and highway transportation are the two primary modes of ground travel in the United States and each serves a vital function in maintaining the economy and mobility of the nation. When a railway and a highway cross at grade, however, and are forced to share the space that constitutes the crossing, very serious safety problems arise.

Grade Crossing Problems

Rail transportation found its beginning in 1830 when the Baltimore and Ohio constructed 23 miles of track and began operations with horse drawn rail cars (35).* Today there are more than 210,000 miles of rail tracks and 3.7 million miles of public roads and streets crisscrossing the country (35). These two transportation modes combine to create 223,243 public at-grade crossings (20), or slightly more than one crossing for every mile of rail track. Of these 223,243 grade crossings, 21.8 percent (48,528) are protected with active devices, including automatic gates, audible and/or visible signals, trainmen or watchmen. The

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*Numbers in parentheses refer to listings in the Bibliography.

remaining 78.2 percent (174,715) are protected only with passive signing or are totally unprotected (20).

In 1971, according to statistics from the Federal Railroad Administration, 3392 grade crossing accidents occurred in this country, involving collisions of trains with pedestrians, automobiles, trucks, buses, motorcycles, and other vehicles or machines (19). In these accidents 1356 lives were lost and 3332 persons were injured (19). Over the 10 year period of 1962 through 1971, the average number of grade crossing accidents was 3667, resulting in 1486 fatalities and 3627 injuries (19).

The serious nature of grade crossing accidents stems not from their frequency, but from their severity. On the average, at least one traffic accident occurs at each crossing every 22 years, and a train involved accident every 69 years (60). Actually, less than one tenth of one percent of all motor vehicle accidents occur at grade crossings annually, and yet they account for approximately two and one half percent of all motor vehicle deaths (60).

The grade crossing problem in Indiana is particularly acute. In 1970, Indiana recorded 94 grade crossing deaths and 445 injuries (34). There are nearly 12,000 miles of rail lines and upwards of 90,000 miles of streets and roads in the state (3). Of the 10,863 public grade crossings in Indiana, 27.7 percent (3004) are actively protected, while the remaining 72.3 percent (7859) are protected with passive

devices (20). This places Indiana, in comparison with the other states, third in number of crossings and fifteenth in percent of crossings having active protection (20). Indiana ranks fifth in the number of annual grade crossing fatalities, based upon the four year average for 1967 through 1970 (20). In 1970, grade crossing accidents accounted for only 0.37 percent of all motor vehicle accidents in Indiana, but resulted in 6.01 percent of all fatalities (compared to 3.0 percent nationally) (3) and 0.59 percent of all injuries (34).

Of all vehicle-train collisions taking place in the United States in 1971, 42 percent occurred at crossings displaying active warning, while 58 percent occurred at passively protected crossings. Sixty-three percent happened during daylight hours while 37 percent took place at night. Those collisions occurring in clear weather made up 69 percent of the total, while the remaining 31 percent took place under cloudy or inclement weather conditions (19). Higher vehicle speeds in rural areas manifest themselves in more severe accidents. In Indiana, for example, during the period 1966 through 1968, rural grade crossing accidents comprised only 31 percent of the total, but resulted in 56 percent of the fatalities (34).

Schultz (53) and Berg (8), studying rural and urban grade crossing accidents respectively, concurred in their findings that accident victims were typically young males,

residing in the city or county of the accident occurrence, were driving in clear weather and had not been drinking. Voorhees agrees that 80 percent of the drivers involved in grade crossing accidents reside within 25 miles of the accident scene (60). Voorhees goes on to state that the incidence of vehicle-train accidents is twice as high in winter months as in summer months (corrected for fuel consumption), and that considerable variation exists in accident rates during hours of darkness, with the peak hazard occurring from 2 a.m. to 4 a.m. Of all the accidents taking place at grade crossings, only about one third involve a train. Another one third occur when a train is present but not involved, and the other third occur when a train is not even present (60).

There are many groups of people concerned about solving highway-railway grade crossing problems, including highway and railway interests, public officials, law enforcement agencies, truckers, traffic research experts, educators, and, foremost, the public (37). A recent study by Urbanik (59) disclosed that the driving public considers grade crossings to be relatively more hazardous than, in order, vehicle crossings where they are (a) the through vehicles, (b) required to yield, (c) required to stop by a stop sign, and (d) required to stop by a traffic signal. Highway curves were considered to be even less hazardous. It should be noted, however, that the respondents considered only four

of the six highway situations to be even moderately hazardous. In relation to priorities for the spending of highway taxes, respondents thought improvements should be made in the following order: railroad grade crossings (considered very important on an absolute scale), road surfaces, painted lines, directional signs, provision of emergency telephones, more traffic signals, roadside rest areas, and roadside grass mowing. (The items mentioned were the only ones to be rated by the respondents.)

Protective Devices and Factors Influencing Safety

There are many factors which are generally considered to affect safety at highway-railway grade crossings. Among those most commonly agreed upon are average daily highway traffic, average daily train volume, type of protection provided, environment (urban or rural), gradient, number of traffic lanes, angle of crossing, weather and visibility conditions, distractions and obstructions (8,53,60). The three principal categories of factors influencing safety are considered by Voorhees (60) to be 1) the vehicles, 2) the physical conditions, and 3) the driver.

The Vehicles

The vehicles involved, although both travelling on the ground, are vastly different in their operating characteristics. The path of a train is restricted to rails, and because of its size and mass, acceleration and deceleration

are practically nil. Because of this almost complete lack of evasive maneuvers available to trains, they have historically been given right-of-way at grade crossings.

Highway vehicles, on the other hand, are much more maneuverable. Within limitations, a highway vehicle may accelerate and decelerate quickly, and turn in order to avoid collisions. The evasive actions of a vehicle are dependent, however, upon the will of the driver to take such actions, which in turn depends on the information available to him. Actual vehicle defects have been found to contribute a very insignificant amount to total grade crossing accidents (60).

The Physical Conditions

Physical conditions might be described as the total environment in which the vehicles are operating. Included herein are such items as weather conditions, gradients, other vehicles which are present, obstructions, sight distances, condition of the crossing, and so on. Probably the most important physical condition relative to safety, however, is the type of protection provided for the crossing.

Protection devices have as their purpose to inform the motorist of his responsibility at the grade crossing. They are broken down into two broad categories: active devices, or those which actually indicate the approach of a train, and passive devices which merely indicate the presence of

a crossing.

Richards and Bridges (47) have written that there are two important decisions relating to sight distance that a driver must make when approaching a passively protected grade crossing. First, he must determine if he has sufficient visibility of the crossing and of approaching trains to allow him time to stop safely before the crossing. Second, he must determine if he has sufficient visibility of approaching trains in order for him to proceed safely over the crossing. The latter decision must also be made by drivers who stop at a crossing, and is especially important to drivers of vehicles which make mandatory stops at grade crossings and take a relatively long time (about 11 seconds) to traverse them from a stopped position.

At an actively protected crossing, on the other hand, the motorist's obligation is to observe and respond to the device upon its activation by an approaching train. His decision-making process is thus reduced to a simple response to a signal that means "stop." Because of this simpler decision, accident experience is better at actively protected crossings than at those with passive protection (60).

The adequacy of these protective devices is far from complete, as is evidenced by the accidents which occur. Michael (42), in summarizing recent research for the American Railway Engineering Association, stated that one of the most important and recurring findings of this research is that "the major safety problem is that drivers involved are

not becoming aware of approaching trains until after they have passed their final opportunity to safely stop." Hopkins and Hazel (31) add that the driver who is speeding, inattentive, fatigued, or driving in inclement weather is especially prone to not perceiving an approaching train. Voorhees (60) concurs that "the driver is simply not seeing the train soon enough before it reaches the crossing."

The need for effective warning devices is clearly demonstrated by Robinson (49) when he states:

> Thus (driver) education, reasonable regulations, and good enforcement are essential and will be helpful, but are not a substitute for reducing the degree of risk through eliminating conflicts or by giving the driver more complete and accurate information.

This "complete and accurate" information comes, for the most part, from warning signals and signs. Voorhees (60) has stated that warning signs should be designed to provide the driver, through shape and message, with information to aid in his safe negotiation of the crossing. As guide lines for the role of grade crossing signing he offers the following (60):

1. Inform him (the driver) prior to the crossing exactly what his obligation will be (i.e., should he observe an automatic device which will inform him of a train's approach or is it his complete responsibility to look for approaching trains).

2. Emphasize at the crossing, when automatic devices are not present, that his responsibility is to determine the existence of trains in such proximity to the crossing as to consitute a hazard.

3. Provide him with additional information necessary for his safe negotiation of the crossing (e.g., reduce speed because of poor sight distance).

4. Provide him with no information when no hazard exists. If the crossing has been abandoned or is used only infrequently by rail traffic, do not use signs which the driver associates with trains.

If all crossings of highways and railways were grade separated, there would be no train-car conflicts and thus no collisions between the two. The vehicle-vehicle conflict would also be eliminated. As previously mentioned, about two thirds of all grade crossing accidents do not involve a train. These collisions are due to the turbulent effect which a grade crossing has on the traffic stream. In the vicinity of a crossing, average highway speeds are lower but there are fewer vehicles in the pace, causing greater speed differentials between vehicles. Where greater differentials occur, the potential for vehicle-vehicle accidents is increased. Thus it is seen that grade crossings create a greater potential for such accidents than do normal sections of highway. Vehicles which are required by law to stop at all railroad grade crossings account for 13 percent of all non-train involved collisions (60). This has led to controversy over the advisability of mandatory stop laws for such vehicles. In sum, if each crossing of highway and railroad was provided with a grade separation structure, there would be no grade crossing accidents due to vehicle-train or vehicle-vehicle conflicts. Roadside obstructions

and structural hazards, however, would be increased and might result in some accidents.

The cost of grade separation structures is very high, however. Estimates of average cost for such structures range from $100,000 (60) to $367,000 (48); thus grade separation is rarely justifiable on an economic basis alone. Grade separation of all crossings in the United States would cost well in excess of $100 billion, more than the government has spent on all highways since World War I (37). Even if funds were available for such a project, an expenditure of this sort would not be prudent, recognizing other national priorities where the money could be put to more effective use.

The situation then reduces itself to the problem of providing the best possible protection at grade crossings. The vast majority of crossings in this country are protected by three standard devices: crossbucks, flashing light signals, and flashing light signals in conjunction with crossing gates. Each of these devices carries with it inherent increases in safety and cost. Schoppert (51) determined the costs to be as follows: crossbucks, $150 initial cost; flashing lights, $10,675 initial cost, about $800 recurring annual cost; gates, $24,111 initial cost, about $1200 recurring annual cost. Other authors have reported different figures, but are in relative agreement with Schoppert. Hopkins and Hazel (31) point out that

"total materials cost in an installation represents only one quarter of the real total cost, and the signal hardware itself represents only three percent of the real total."

Protection coefficients for the various types of protection have been developed by several authors. These protection coefficients are numerical ratings of the measure of protection afforded by each device. Table 1 displays the ratings reported in several studies. Crossbucks are used as a base condition and the coefficient for them is set to unity. A lower numerical rating indicates more protection. It can be seen that crossing gates have always been found to be the superior method of protection, and are generally about twice as effective as standard flashing lights. Crossbucks are by far the inferior method of protection.

In recent years, there has been much debate over the use of stop signs at highway-railway grade crossings, and findings relative to their use have often been in conflict. Schultz (53) reports that recent studies have shown excellent compliance by drivers for stop signs at grade crossings, and that in some cases accidents have been reduced by as much as 90 percent. This finding is reinforced by Voorhees (60), as he gives stop signs a protection coefficient of 0.58 as compared to 1.00 for crossbucks and 0.20 for flashing light signals. Bezkorovainy and Holsinger (10), in a driver compliance study conducted in Lincoln, Nebraska, found that driver compliance to stop signs at grade

Table 1. Protection Coefficients for Standard Warning Devices as Reported in Several Studies.

	Author and Reference				
	Voorhees (60)	Thomas (55)	California Public Utilities Comm. (1)	Schoppert (52)	McEachern (41)
Crossbucks	1.00	1.00	1.00	1.00	1.00
Flashing Light Signals	0.20	0.23	0.21	0.3-0.6	0.333
Gates and Flashing Lights	0.11	0.22	---	0.1-0.2	0.133

crossings was poor when compared to compliance at vehicle intersections, and concluded that such installations encouraged willful violations and created contempt and disrespect for all stop signs. It should be noted that much of the controversy over the use of stop signs at grade crossings is due to the unnecessary delay caused to motorists. It is questioned whether it is justified to force all vehicles to stop, if adequate visibility of trains is available, when only a small percentage actually encounter a train.

Priorities for improvement of grade crossings are usually developed using accident prediction equations or hazard equations. These equations are formulated to predict the number of accidents possible at a particular crossing

over a given period of time, and to rank crossings in their relative need for improvement. Most of these equations take basically the same form. For example, the state of Indiana presently uses the following formula (3):

$$HI = VTP$$

where

HI = the hazard factor
V = the average daily traffic volume
T = the average daily train volume
P = the protection factor (values similar to those in Table 1)

Bezkorovainy (9) applied eleven hazard index formulas to 180 crossings in Lincoln, Nebraska, and concluded that all formulas gave basically the same ranking of crossings according to their accident potential. He also warned that such formulas should not be applied to compare two or three crossings, but may be used to successfully rate a large number of crossings according to their inherent hazard. It is noted that these techniques are useful for deciding which crossings to improve with available funds, but it must be kept in mind that railroad grade crossings are only one type of highway intersection, and improvement programs must be kept in perspective with the expected benefits and costs of other highway improvements (12,60).

The Driver

It is commonly agreed that the motor vehicle operator is the most variable and unpredictable factor contributing

to grade crossing accidents (60). It has previously been stated that if all crossings were grade separated, no grade crossing collisions would occur. Hays (29) argues that by the same token "there would be no grade-crossing collisions if all drivers of motor vehicles complied with existing laws and regulations and, under the dictates of ordinary common sense, exercised proper caution at grade crossings."

Adding credence to Mr. Hays' argument is a report from the Association of American Railroads (5) which stated that the principal cause of grade crossing accidents was the failure of drivers to exercise due caution or to observe and obey safety laws and regulations. Stricter enforcement of such laws and regulations would most assuredly reduce the number and severity of grade crossing accidents (8,10, 29,60).

The Uniform Vehicle Code (44), in Chapter 11, Article VII, Section 11-701, clearly delineates the driver's responsibility when encountering a grade crossing:

> Whenever any person driving a vehicle approaches a railroad grade crossing under any of the circumstances stated in this section, the driver of such vehicle shall stop within 50 feet but not less than 15 feet from the nearest rail of such railroad, and shall not proceed until he can do so safely. The foregoing requirements shall apply when:
>
> 1. A clearly visible electric or mechanical signal device gives warning of the immediate approach of a railroad train;
>
> 2. A crossing gate is lowered or when a human flagman gives or continues to give a signal of the approach or passage of a railroad train;

> 3. A railroad train approaching within approximately 1500 feet of the highway crossing emits a signal audible from such distance and such railroad train, by reason of its speed or nearness to such crossing, is an immediate hazard;
>
> 4. An approaching railroad train is plainly visible and is in hazardous proximity to such crossing.
>
> No person shall drive any vehicle through, around or under any crossing gate or barrier at a railroad crossing while such gate or barrier is closed or is being opened or closed.

Many studies have found it difficult to explain the occurrence of highway-railway grade crossing accidents, thus lending further support to the argument of driver variability. After measuring 56 variables at 289 accident locations and 28 of those 56 variables at 241 non-accident locations, Schultz (53) applied the techniques of regression and factor analysis to the data. He found that only 20 percent of the accident occurrence could be explained. This led him to infer that grade crossing accidents are the result of driver characteristics and/or chance (53).

Perhaps the best explanation of this driver variance, and a means for its possible reduction, are put forth by Conner (12):

> The driver's attitude toward train conflicts varies considerably. As trains are very seldom encountered by him in his normal driving tasks he becomes unconcerned with the possibility that he may encounter a situation that is dangerous to him. Then when the dangerous situation is presented to him he is both awed, and frightened by it. In this condition he is not likely to act in a predictable or rational manner.

> We cannot expect to change the driver's actions once he gets into a dangerous situation, but with improved signing techniques we may be able to improve his attitude and attentiveness in the vicinity of the crossing area.

Summary

Possible solutions to the highway-railway grade crossing problem, then, lie in several areas. If a crossing can be separated in grade, it will no longer present vehicle-vehicle or vehicle-train conflicts. If the crossing cannot be eliminated, the driver must be presented with the most accurate information possible regarding his responsibility and the existing conditions at the crossing. He must receive this information in sufficient time before the crossing in order that he may make the best decision as to the action he should take, and have time to take that action safely. Finally, through driver education and enforcement of grade crossing laws and regulations, the driver must be impressed with the danger inherent in every grade crossing he encounters.

Areas of Investigation

This study was undertaken to investigate two aspects of highway-railway grade crossings. First, a review was made of innovative, or non-standard types of active grade crossing protection. Various devices were considered, including those which have actually been used and tested, and those which have only been proposed or are still in design

stages. The need for such devices and their role in grade crossing protection was also reviewed. This information is contained in Chapter II.

Second, a project was initiated to evaluate driver performance and reaction to various active additions to standard flashing light signals at an extremely hazardous grade crossing in Indiana. These additions are planned to include overhead red alternating flashers, overhead crossing illumination, and automatic crossing gates with high intensity flashers on the gate arms. Description of the data collection procedure and analysis of the data collected for the base condition are included. This material comprises Chapter III.

The specific objectives of this research were:

1. To review and gather information on all innovative active protection devices for highway-railway grade crossings, including the evaluation of their effectiveness where possible.
2. To design a data collection system which would allow the gathering of the data required to effectively analyze the impact of various crossing protection improvements.
3. To collect and analyze data on the performance of motorists as they approached a crossing protected by standard flashing light signals.

CHAPTER II. INNOVATIVE ACTIVE PROTECTION DEVICES

In recent years, many researchers (8,31,42,51,60) have voiced the need for new highway-railway grade crossing protective devices which would be significantly lower in initial and recurring costs than an upgrading of protection to the next highest level (e.g., from flashing lights to gates), and yet afford a comparable increase in protection for the motoring public. Means of fulfilling this need are explored in this chapter.

Innovative crossing protection devices can be categorized into active and passive classes, and further subdivided into advance warning and "at the crossing" devices. The need existing in each of these four groups is clearly demonstrated by Michael (42), who when summarizing recent research observed that:

> 1. Advance warning to the motorist at an approaching railroad crossing and (informing him of) his responsibility throughout are today generally inadequate.
>
> 2. There is a need for the development of low-cost protective devices, of both the railroad ahead warning type and the train-approaching warning type.
>
> 3. Motorists need to be more impressed with the importance of the train-vehicle hazard.

Passive warning could be improved in several ways. The standard round advance warning sign (a yellow disk, 36 inches

in diameter, carrying a 90-degree crossbuck and the letters RR in black) is considered by many officials to be inadequate (50,58). Schemes of redundant advance warning signs, proposed by Voorhees (60), would differ in color, shape and message depending upon the type of warning used at the crossing (active or passive). There is general concern for more conspicuous signs in advance of and at the crossing which would be readily observed by the motorist, and would impress upon him the eminent danger associated with the railroad crossing.

It is commonly agreed, however, that the greatest potential for effective new grade crossing protection rests in the area of active devices. Voorhees (60) notes that "a simple, inexpensive active device would solve many of the problems...by decreasing costs and therefore allowing them to be installed at a greater number of crossings." He goes on to state that "if every grade crossing could be protected with an active device the problems experienced could be reduced to minimum levels." Schoppert (51) offers that such low-cost devices could effectively fill the existing void of active protection at locations with relatively low hazard.

Many non-standard active protection devices have been installed or proposed, and some of these are discussed in subsequent sections. Relatively few of these innovations, however, have been field tested and evaluated for driver reaction and compliance. The difficulties encountered in

endeavoring to implement new concepts in grade crossing protection are well described by Hopkins and Hazel (31):

> If the new system in some way conflicts with the operation of the original, very severe problems will result; no railroad is likely to risk an accident with an admittedly experimental protective system, and no other body (such as government) can be expected to accept full liability, particularly in this difficult area. (A common aspect of lawsuits is the alleged failure of the signals.)
>
> This difficulty is met directly when new signal devices, rather than activation techniques, are considered. In this second case, one must consider not only the technical operation, but how motorists will respond to a different means of indicating the imminent passage of a train. The victim of an accident under these circumstances may have a legitimate complaint that he did not understand the meaning of the warning. One can imagine the legal complexities which would result. Thus, beyond the question of reliability, any system which presents a significantly changed aspect to the motorist poses a real challenge in the evaluation of its effectiveness, not only in devising and interpreting tests, but also in implementing them in actual service.

The functional requirements of grade crossing protection, as with other types of highway signs and signals, are conspicuity (must be perceived), clarity (must be understood), and credibility (must be believed). Several innovative devices which attempt to surpass conventional methods in meeting these requirements are now discussed.

Implemented Active Advance Warning Devices

This section includes several innovative advance warning devices which have been installed in actual service and are either activated through rail circuitry or are in continuous operation.

Three Horizontal Yellow Flashers

In Los Angeles, California, flashing light signals and automatic gates were installed at a particular crossing, and special advance warning devices were placed approximately 400 feet from the crossing on each approach. These devices consisted of three yellow flashing light units placed horizontally, similar to a traffic light unit placed on its side. It is assumed that this device was used in conjunction with a standard advance warning sign. The center light flashed continuously until a train was in the track circuit controlling the gates, at which time the center light went out and the outer two lights flashed alternately. Accident experience after the installation at this location was reported as normal; no other measure of reported effectiveness could be found (18).

Neon "RXR GATE" Sign

Automatic gates and flashing light signals were installed at a crossing in Tracy, California in 1955. During the next two years there were 39 and 49 accidents respectively, involving collisions with the gates. Special advance warning signs were then placed at 800 feet from the crossing on each approach. These devices consisted of a flashing yellow light and a 24 by 48-inch neon sign displaying the symbol "RXR" over the word "GATE". The entire device was activated using existing track circuitry. Collisions with the gates were substantially reduced; over the next three years there were

an average of only 16 such accidents annually. This reduction in accidents was attributed to the advance warning device (18). Also, at several locations in California, similar neon signs displaying only "RXR" were placed 600 to 700 feet in advance of the crossing. These were employed as interim devices, and were removed as crossing protection was upgraded (57).

Flashers on Stop Signs

Red flashing lights have been used to draw attention to standard stop signs at some grade crossings. Flashers are used singly or in pairs in various configurations about the sign. These flashing lights may be in continuous operation or activated by an approaching train (18,22). No evaluation of the effectiveness of these flashers could be located.

Neon "RR SIGNALS AHEAD" Sign

The State of New Jersey made at least one installation of this type, 500 feet in advance of a particularly hazardous grade crossing. The sign was eight feet by three feet with 10-inch red neon letters on a black background stating "RR SIGNALS AHEAD." The sign was supported on the left side of a divided highway, extending eight feet over the roadway, and was activated to flash continuously five seconds before to five seconds after the standard flashing light signals at the crossing were activated. No evaluation of effectiveness has been reported (57).

Cantilever Red and Yellow Flashers

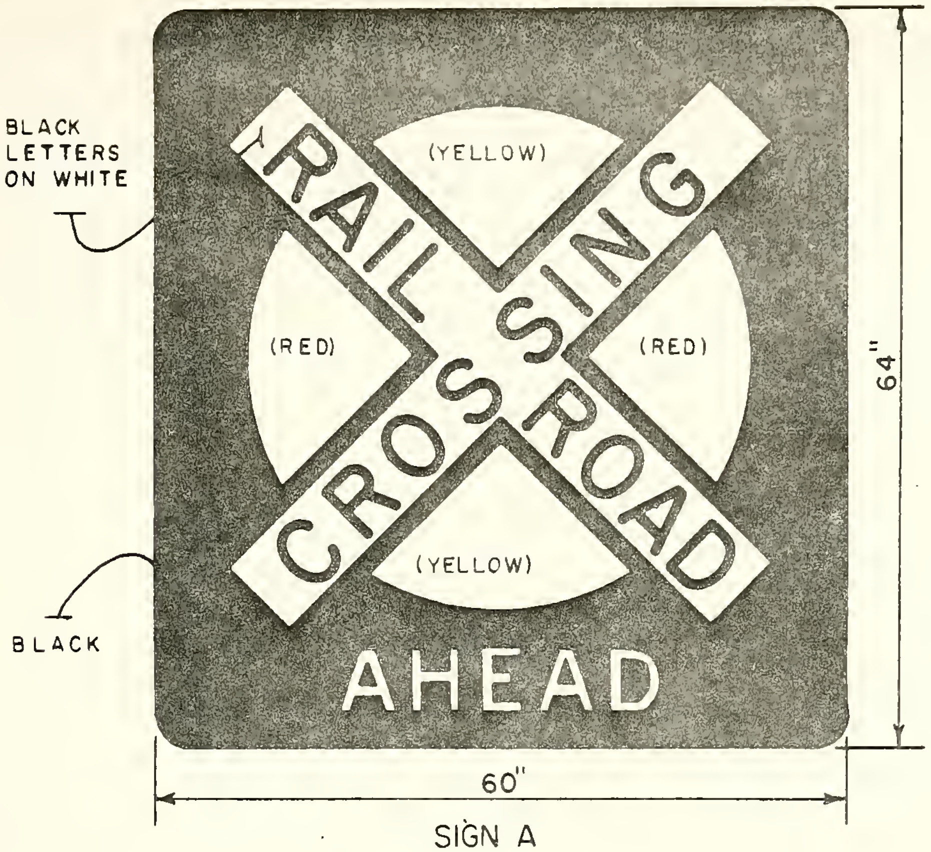
Track-activated beacon flashers have been tried in Indiana. These flashing light units, which were placed approximately 50 feet in advance of the crossing, were supported on mast arms over the roadway. Two amber beacons flashed continuously until preempted by an approaching train, at which time two red beacons flashed alternately. Tests for effectiveness were not reported (57).

Yellow Flashers on Standard Advance Warning

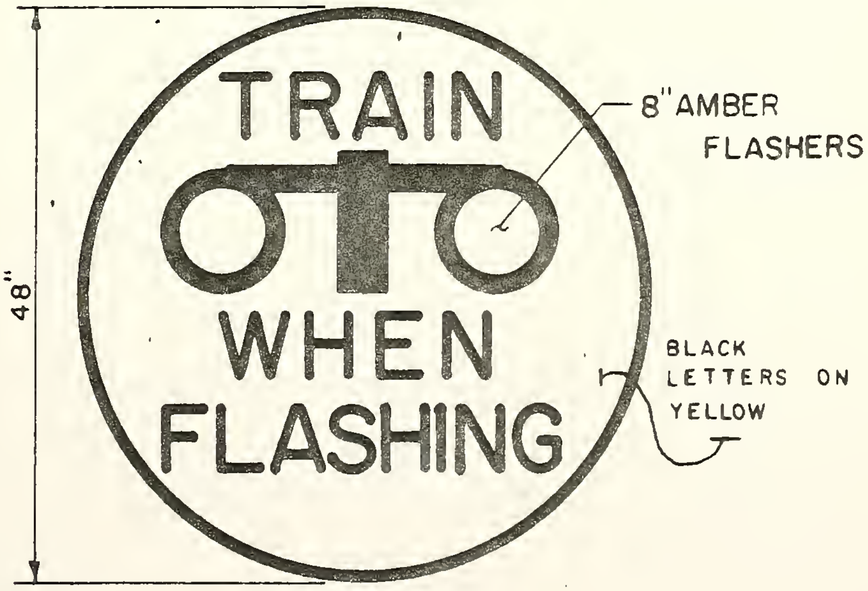
Several states have installed one or more yellow flasher units on the standard advance warning sign. These yellow flashing lights may be mounted in various relative locations about the sign and may be operated continuously or activated simultaneously with active crossing protection. This use of yellow flashers, recognized by drivers as a warning to use caution, is particularly useful at locations where the crossing protection is not visible at the advance warning sign (57,58).

Texas System of Advance Warning

Probably the most recently implemented step forward in active advance warning was initiated in 1970 by a Railway Highway Grade Crossing Diagnostic Team in Texas. This team has designed and installed a series of two advance warning signs at 14 locations in their state. These signs are shown in Figure 1. Placement of the signs depends on highway



SIGN A



SIGN B

FIGURE 1. TEXAS SYSTEM OF ADVANCE WARNING

vehicle speeds, with Sign A placed first, and Sign B placed between Sign A and the existing active crossing protection. Sign B has two alternating amber flashers which are activated in conjunction with the crossing protection. Detailed analysis of the effectiveness of this advance warning system is planned, but no results are yet available at this writing (40).

Proposed Active Advance Warning Devices

In this section several new concepts in activated advance warning are considered which at this time have not been implemented but which may prove to be useful in supplying the motorist with much-needed information concerning what to expect at an upcoming grade crossing.

Illuminated "STOP AHEAD" Sign

An illuminated "STOP AHEAD" sign has been proposed in the City of Chesapeake, Virginia, to be used in conjunction with the standard railroad advance warning sign. This device would begin flashing prior to the activation of crossing protection in order to allow vehicles to stop comfortably before the crossing. The message would be carried in six inch red letters. This device is expected to be especially useful on roads carrying a high volume of traffic at high speeds (11).

In-Vehicle Real Time Information

Recent advances in electronics technology capabilities have spurred interest in supplying motorists with real time

information concerning their driving environment through in-vehicle audio or visual messages. Although such systems have not yet been applied specifically to railroad grade crossings, this would certainly be a logical extension of such research.

Several experiments have been conducted using roadside radio transmissions to provide drivers with information regarding traffic conditions (14,15,21). Short range radio signals are transmitted by a buried cable near the roadway. These broadcasts may be received by regular car radios or on special receivers.

One such communications system, developed by General Motors Corporation, is Driver Aid, Information and Routing (DAIR) (21). Although this is a very sophisticated system, involving two-way communications in informing the driver of traffic and speed conditions, as well as providing automatic routing for his trip and allowing him to summon emergency help, a subsystem of DAIR is the simple roadside communication link. This link allows broadcasts of preprogrammed messages concerning traffic conditions and special hazards. A radio communication system, based on this DAIR subsystem and tested on the Kentucky Turnpike, met with favorable user acceptance (14,15).

In-vehicle visual displays may also be used to supply real time information. The Experimental Route Guidance System (ERGS) (56), also developed by General Motors, is

one such system. Routing directions are supplied on a dashboard visual display, once the driver selects his destination. Instructions are supplied as to which lane to use, where to turn, and so on, and driver errors such as a missed turn are readily known. An improvement over dashboard display of information is the head-up display (7), developed as an airplane pilot aid, which superimposes a virtual image over the real world. Thus a driver may read the message without taking his eyes from the road, and without undue distraction or blocking of vision.

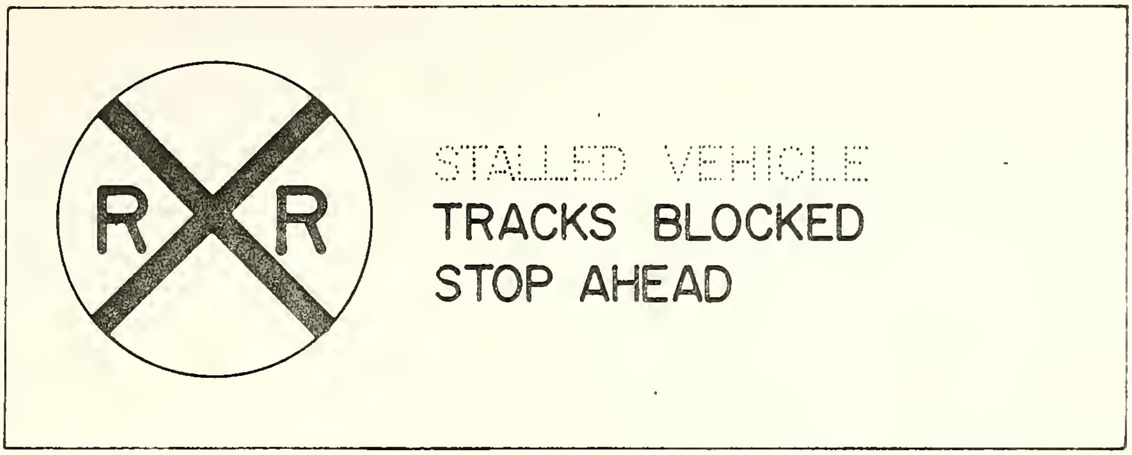
The application of in-vehicle real time information to highway-railway grade crossings is evident. The motor vehicle operator could be informed of an approaching train, a train already blocking the crossing, or stopped vehicles in the traffic lanes. This information would be a valuable aid in his safe negotiation of the crossing.

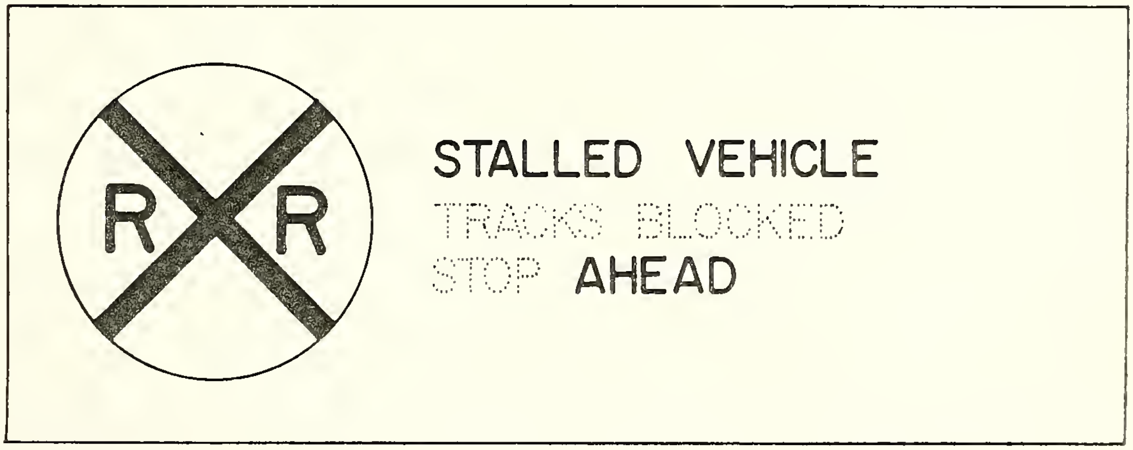
Variable Message Sign

Another method of providing the driver with real time information is through the use of a variable message sign. Variable message signs may display two or more alternative messages depending on traffic and roadway conditions. The Chicago Area Expressway Surveillance Project has conducted considerable research using electronic variable message signs to provide real time information on the Eisenhower Expressway and its access ramps (30).

Urbanik (59) has proposed a design for an overhead variable message sign for use at highway-railway grade crossings. This sign would extend completely over two lanes of a four lane divided highway and display one of three messages as shown in Figure 2. The round advance warning sign would remain illuminated at all times. The messages indicating a hazard (i.e., "tracks blocked stop ahead," and "stalled vehicle ahead") would flash in red letters when activated, and the remaining message ("tracks ahead") would be lighted continuously in amber when there was no immediate hazard. The sign would be located so as to allow safe stopping sight distances for all vehicles; letter height would be 16 inches. Simultaneous activation with the existing crossing protection was recommended, with the provision of special activation devices which would provide a constant warning time of 20 seconds regardless of train speed.

This advance warning device was proposed to be most beneficial in locations with high speed and volume vehicle and train movements and bad accident records. Grade separation might normally be warranted at such locations, but this warning device might give comparable protection at only a fraction of the cost. A research project was recently (1972) proposed at Purdue University to construct and install this device along with an elaborate data collection system in order to accurately analyze its effect on driver performance. As of December 1972, approval of the research had not been obtained.





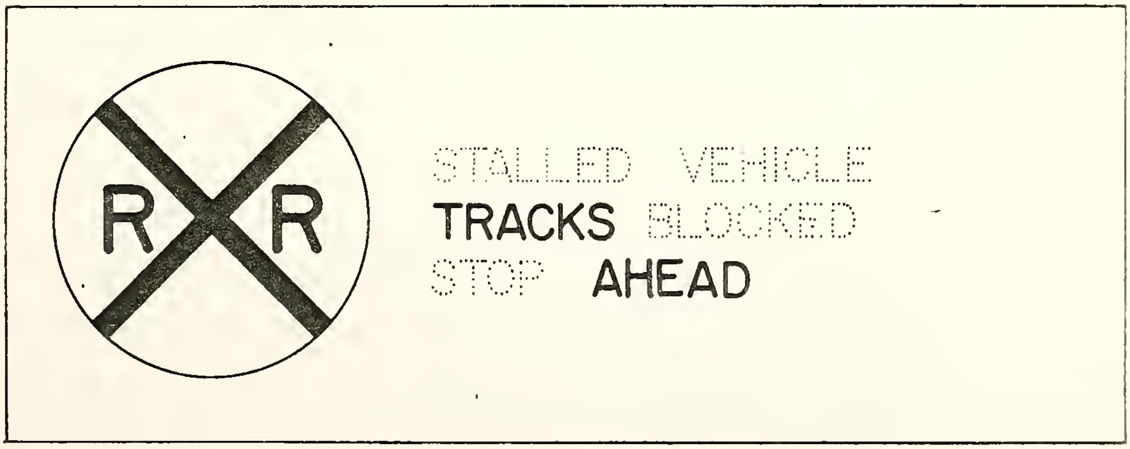


FIGURE 2. MESSAGES TO BE DISPLAYED ON THE OVERHEAD VARIABLE MESSAGE SIGN.

Implemented Active Devices at the Crossing

Active "at the crossing" devices are now considered. These are innovations which have been installed in the field; evaluation of their effectiveness is presented where available.

Ohio Special Lights and Signs

In 1960 the State of Ohio began installing special signs and lights at crossings considered too hazardous for crossbucks but not hazardous enough to justify the installation of flashing light signals. These rectangular signs, 48 by 30 inches, were finished in reflectorizing material carrying white figures on a red background. A large crossbuck with a 12-inch letter R on each side was centered on the sign. Alternating yellow lights flashed continuously above and below the sign (17). In 1965 Ohio abandoned its use of this special sign because of its ineffectiveness, as revealed in a study conducted specifically for its evaluation (58).

Standard Traffic Signals in Lieu of Flashers

Several railroads, with the approval of certain state public utility commissions, have used track circuit controlled standard highway traffic signals at some crossings, one on either side of the track. These signals are used in conjunction with standard crossbucks, but in lieu of flashing light signals. The supposed advantage of such an

installation is that drivers give it far greater attention, respect, and obedience than ordinary flashing light signals (26). Delay to motorists is minimized since the green indication is presented to the motorist unless a train is approaching. Buses and fuel carriers may not be required to stop, as they are at other crossings; therefore the incidence of rear end collisions is greatly reduced. In the early 1960's the Michigan Department of State Highways installed traffic light signals at four railroad crossings on the then new interstate highway system. These signals were employed as interim devices in anticipation of the subsequent abandonment and removal of the crossings. Since that time two of the crossings have been removed and the other two have been grade separated. The decision to use traffic light signals in this situation was not based upon any particular existing accident problem, but rather in an effort to eliminate rear-end collisions caused by vehicles making mandatory stops (13).

Highway traffic signals, operated by railroad switchmen, have also been installed at several switching and industrial crossings (22). No report on the effectiveness of highway traffic signals at railroad grade crossings could be found.

"WAIT - 2 TRAINS" Sign

This device, sanctioned by the Illinois Commerce Commission in 1964, is used to alert motorists to the approach of a second train at crossings with two or more main line tracks. It is used in situations where costly automatic gates might otherwise be warranted. The signal is placed on the vertical mast of a standard flashing light signal, with two 14-inch lenses mounted one above the other. Both lenses are actuated only upon the approach of a second train and are aimed at a driver already stopped for the flashing light signals. The top lens on this signal reads "WAIT" in black letters on a red background; the lower lens reads "2 TRAINS" in black letters on a white background. When activated, the lenses flash alternately.

It was reported that by 1968 eight Illinois railroads had installed a total of 23 signals of this type, primarily on lightly travelled highways. Accident records for like periods before and after these installations revealed a reduction in deaths from two to zero, injuries from 17 to two, and total accidents from 19 to four (23,24,26).

Missouri Blinking Light

In 1967, at the order of the Missouri Public Service Commission, four railroads made one installation each of an "Electric Railroad Crossing Signal." This signal consists of a standard reflectorized railroad crossbuck with a 12-inch yellow beacon continuously flashing above and

below the crossbuck. These flashers were originally burned at 150 watts but were reduced to 100 watts due to complaints that they were too bright. It was suggested that a possible solution might be to operate the lights at a higher voltage during the day than at night to insure visibility of the signal.

After these signals were used for about three years, it became evident that there was confusion among drivers as to their meaning. In 1972 it was reported that the signals had no discernible affect and no subsequent installations have been made (25,27,33).

Rotating Red Light with Wigwag Signal

An experiment was begun in 1968 wherein shielded rotating red lights were operated as a supplement to wigwag signals at two crossings in California. The light was shielded by a hood and thus confined to a beam directed only to highway traffic. Although safety specialists generally oppose the use of rotating red lights on anything other than emergency vehicles, this installation more closely approximated the use of a simple red flasher. As the red light was activated simultaneously with the wigwag signal, it furnished the motorist with improved warning of an approaching train. In 1971, after about three years of operation, it was reported that the test installation was very promising. Particularly during hours of darkness, compliance by motorists was practically unanimous (26,28).

Indiana Green Light Signal

Twenty-seven highway-railway grade crossings in Indiana are currently protected by a green light type signal device. This installation is described as follows (27):

> The regular crossbuck sign is supplemented with a highway traffic "STOP" sign installed on each side of the crossing with an additional sign reading "When Light is Out." Adjacent to the "STOP" sign is an 8 foot mast with back-to-back traffic light units with green lenses. The green light is tied to the railroad's APB block system circuits. The traffic light heads utilize 67-watt 120-volt bulbs displaying a green light to motorists approaching the crossing, provided no train has preempted the XR relay. On the approach of a train, the relay is de-energized and the green light is extinguished. The cost of the installation is less than $1,000. This installation is not considered "fail safe." Further, the "Green Light" stays off longer than necessary on account of the length of the APB block.

Another variation of the device is similar except that it uses a red light as well as a green light and is controlled by ordinary track circuitry. This is basically a standard flashing light signal system utilizing different hardware. The cost, proportionately higher, is over $8,000 (27).

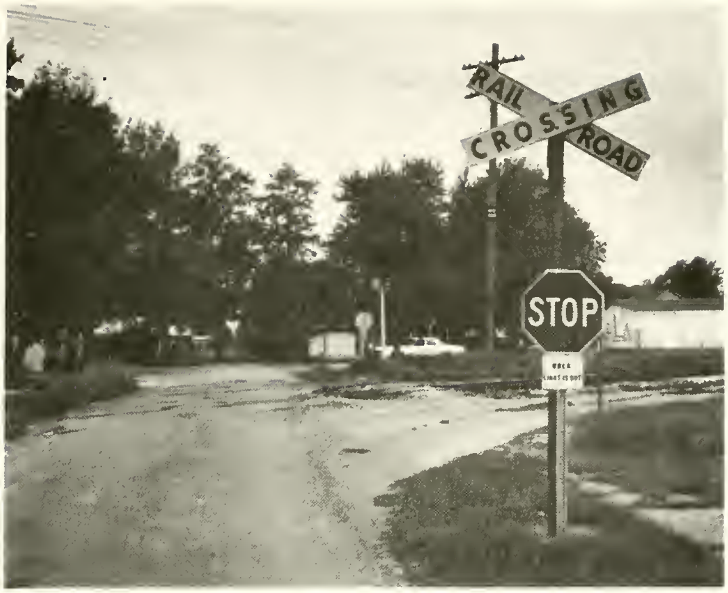
Green light crossing protection is employed at locations where regular crossing protection would not be justified, such as at low traffic volume rural roads, at crossings with poor sight distance, and at some private crossings. None are installed on Federal Aid Secondary or high volume roads. Acceptance by the travelling public has been excellent, even to the extent that they have requested

several of the 27 installations, especially at rural crossings used by school buses. Accident records at these 27 crossings have been "decidedly improved" (27).

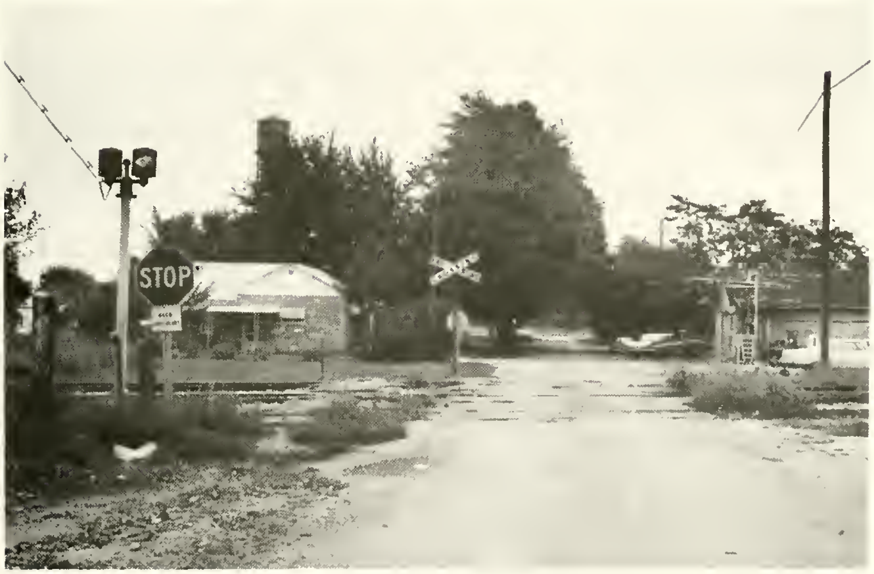
Five Green Light Signals of the type first described were inspected in the field at various sites around the State of Indiana. A description of each of these installations noting deficiencies and operating characteristics follows.

Site 1: Cason Street in Rossville, Indiana. This site is a very lightly travelled urban street on the northern edge of Rossville. Views of the two crossing approaches, showing the relative positions of the crossbuck, the green lights, and the stop sign and "WHEN LIGHT IS OUT" sign are shown in Figure 3. Cason Street crosses three rail tracks at this point. The green light signals and stop sign on Approach B are at a distance of approximately 70 feet from the crossbuck and stop sign on Approach A. Also, the equipment on Approach A is located on the left side of the street. The "WHEN LIGHT IS OUT" sign is relatively small, necessitating being fairly close to it before it is readable. These three factors may lead to driver confusion, especially for a person unfamiliar with the crossing.

The crossing itself is very rough. Drivers who approach this crossing almost unanimously slow their vehicles to 10 miles per hour or less to traverse it, looking both ways while doing so. It is believed that this slowing is



APPROACH A



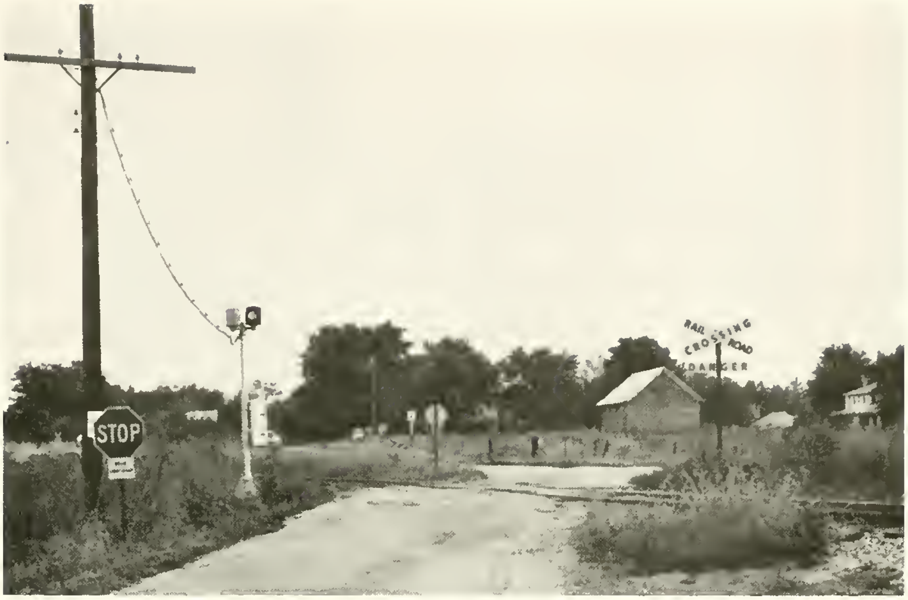
APPROACH B

FIGURE 3. GREEN LIGHT SIGNAL INSTALLATION AT SITE 1: CASON STREET IN ROSSVILLE, INDIANA

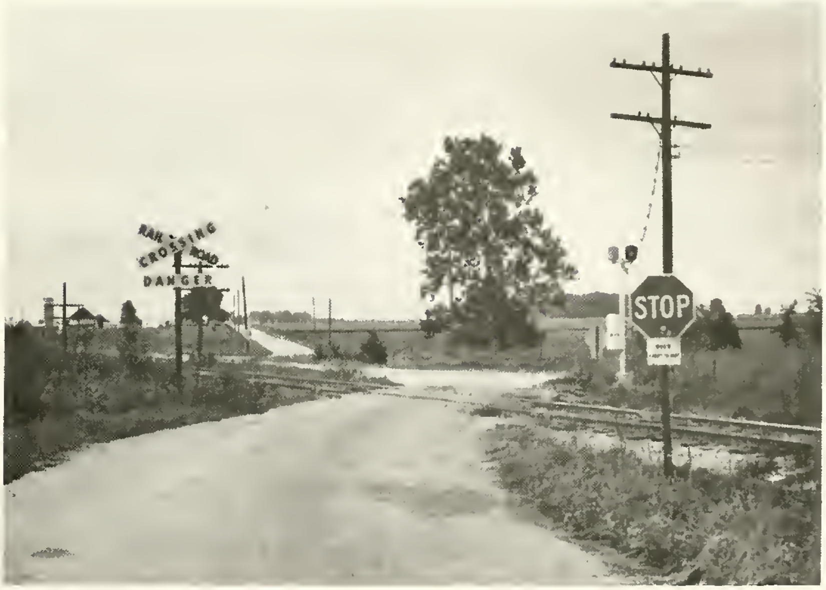
due in most part to the roughness of the crossing. No discernible difference was noted in driver reaction at this crossing as compared to other similar crossings in the area protected only by crossbucks.

Site 2: County Road North of Rossville, Indiana. Views of the two approaches to this crossing are shown in Figure 4. This small road exists from U.S. 421 approximately three miles north of Rossville. The crossing is almost directly adjacent to the main highway (from Approach A), since the rail track parallels the highway. The county road crossing the tracks is actually a loop serving a group of about 30 or 40 residences, and so is very lightly travelled. The two stop signs, green lights and crossbuck are all supported on separate poles, but are fairly well grouped, presenting a unified aspect to the motorist. Vandalism is apparently a problem at this site, evidenced by the bullet holes in the signs on Approach B.

Two factors make it nearly impossible to determine driver reaction to the signal at this site. First, vehicles approaching the crossing are already moving at very slow rates of speed; the vehicles on Approach A because they have just slowed to turn onto this road from the highway, and the vehicles on Approach B because they must stop before entering the highway. Second, the crossing is extremely rough. Drivers traversing this crossing are nearly evenly divided between those who look both ways down the tracks



APPROACH A



APPROACH B

FIGURE 4. GREEN LIGHT SIGNAL INSTALLATION AT SITE 2: COUNTY ROAD NORTH OF ROSSVILLE, INDIANA

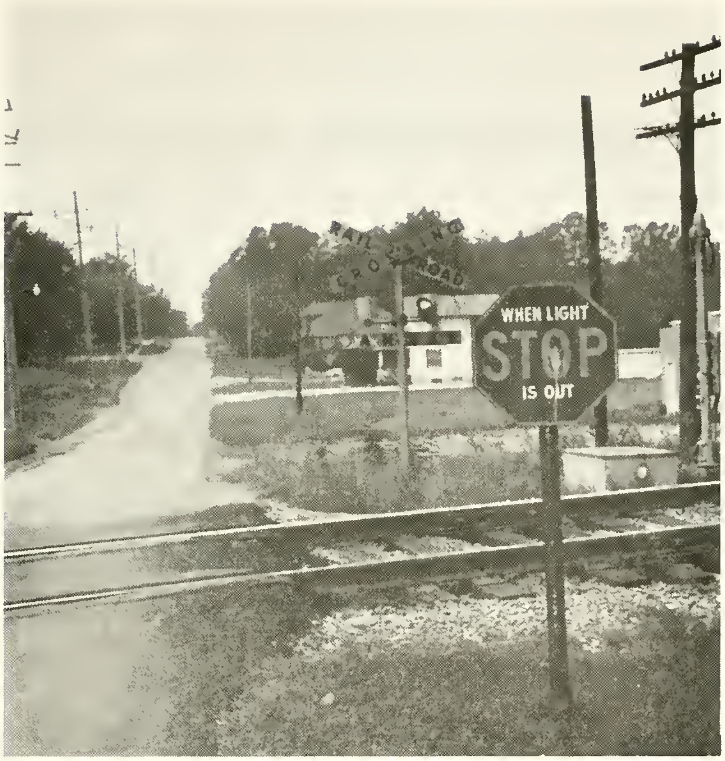
and those who do not. This does indicate some reliance on the green light signal.

Site 3: Main Street in Lowell, Indiana. This installation of the green light signal, shown in Figure 5, differs from the first two in several ways. The message "WHEN LIGHT IS OUT" is painted directly on each stop sign. Also, the green lights are mounted directly beneath the crossbucks on the same supporting pole.

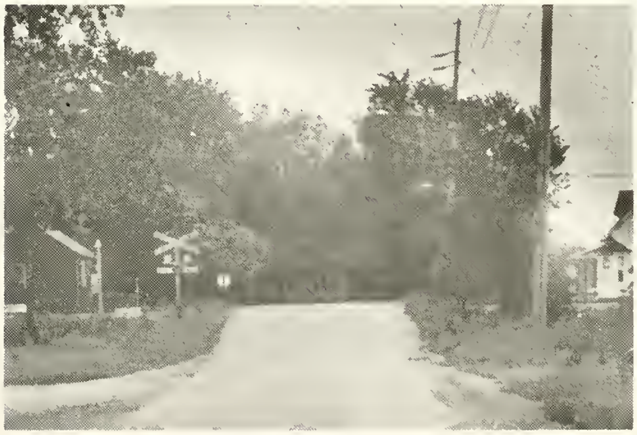
Lack of proper maintenance has taken its toll at this installation. It is noted that on Approach B the stop sign, mounted on the right side of the street, is completely obscured by vegetation until a distance of less than 50 feet from the crossing. The paint on the wooden crossbuck is non-reflectorized and is generally deteriorated. The work of vandals is also evident on both the stop signs and crossbuck.

The crossing, although not particularly rough, is elevated to track level and presents a sizable hump in the roadway. Again, it is difficult to ascertain whether motorists slow down due to expected roughness or because of the crossing hazard. The majority of drivers observed while the green light was on at this location slowed their vehicles to between 10 and 15 miles per hour and looked both ways down the tracks while proceeding over the crossing.

One train was observed crossing this location, travelling at an estimated speed of 35-40 miles per hour. The



APPROACH A



APPROACH B

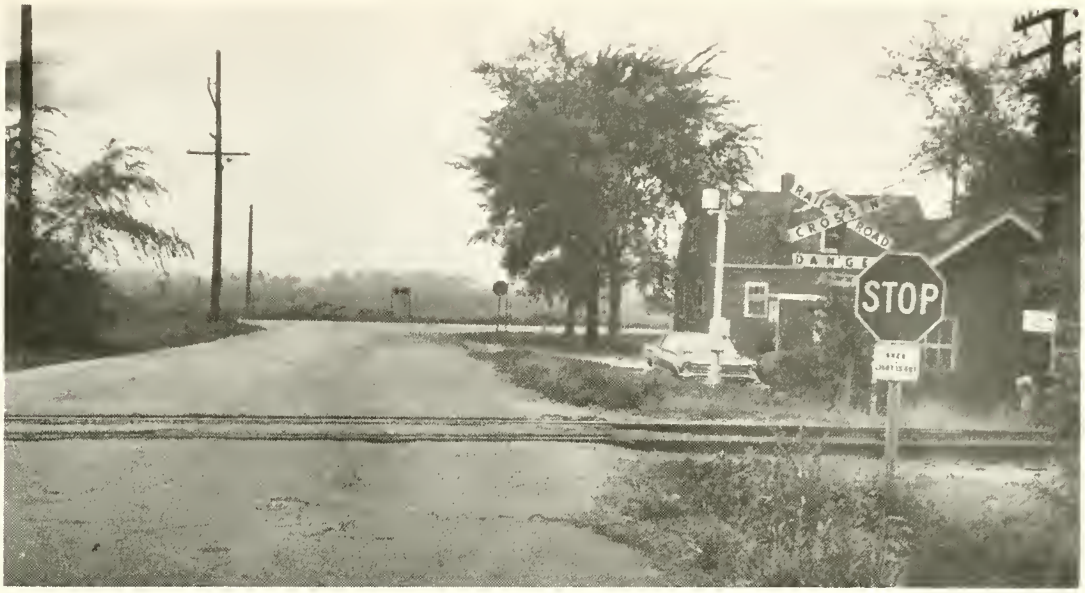
FIGURE 5. GREEN LIGHT SIGNAL INSTALLATION AT SITE 3: MAIN STREET IN LOWELL, INDIANA

green lights were extinguished for more than a minute before the train arrival and remained in this status for about a minute and a half after the train had passed. Vehicles arriving while the signal was activated unanimously slowed to a complete or rolling stop (0-5 miles per hour) and looked for trains in each direction. This is a contrast in crossing speed to vehicles approaching when the light was on.

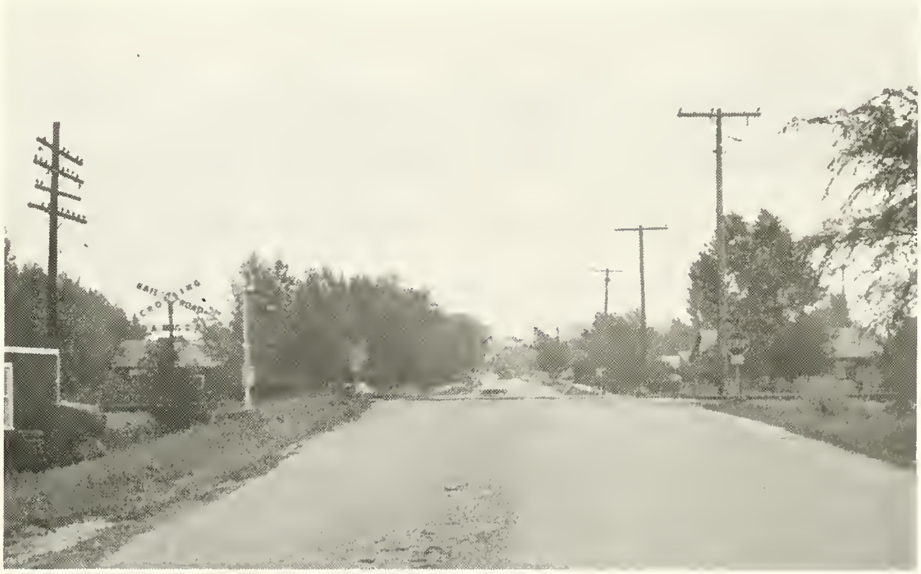
Site 4: 215th Street in Dyer, Indiana. Figure 6 shows views of each approach to this crossing, located in a residential section of Dyer. The crossbuck, bearing deteriorated non-reflectorized paint, is situated approximately 14 feet off the edge of the street, and is obscured from view by tree limbs on Approach A except in close proximity to the crossing. These facts, coupled with a wide street and wide separation of the crossing protection components, may contribute to driver confusion at the crossing.

Cars were observed both when the green light was on and when it was extinguished by an approaching train. In general, the only deviation in driver reaction was that when the light was out drivers slowed to a stop or rolling stop more frequently. The moderate roughness of the crossing necessitated considerable slowing by all drivers, the majority of whom looked both ways for trains.

The approach of the one observed train, with speed estimated at 40-45 miles per hour, provided approximately



APPROACH A



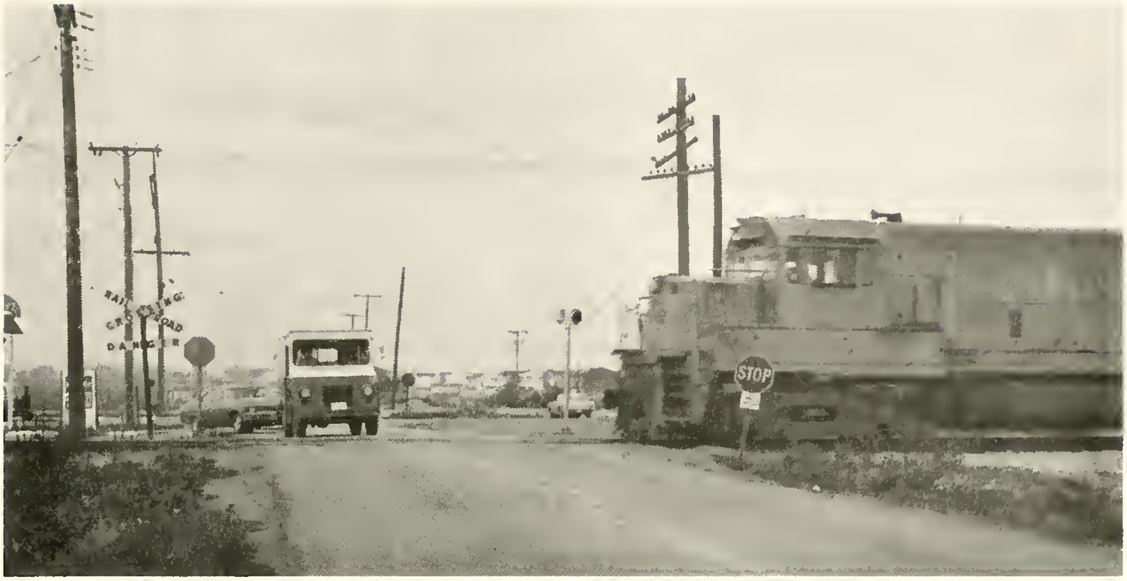
APPROACH B

FIGURE 6. GREEN LIGHT SIGNAL INSTALLATION AT SITE 4: 215th STREET IN DYER, INDIANA

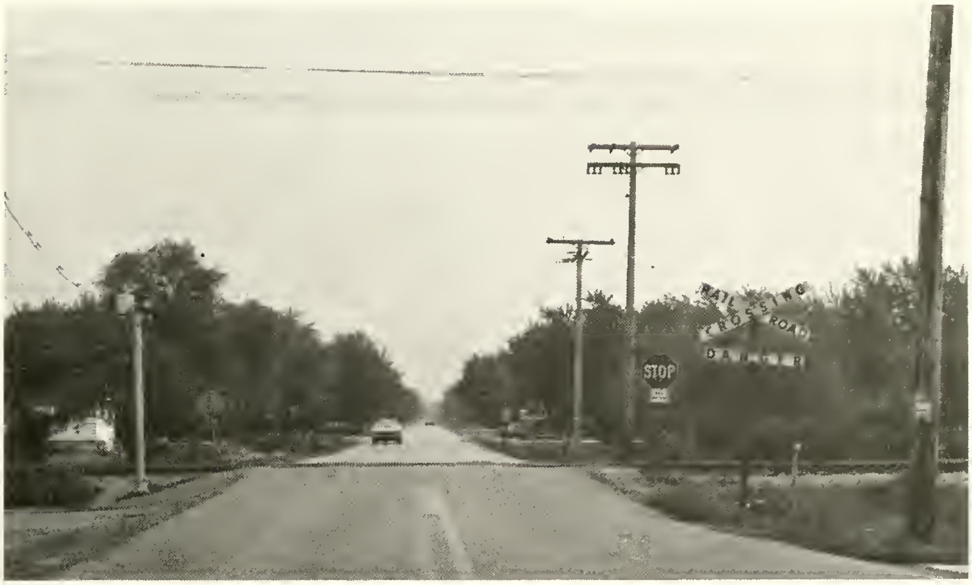
one and one half minutes advance warning and two and one half minutes of activation after it had cleared the crossing.

Site 5: 213th Street in Dyer, Indiana. This crossing (see Figure 7), also located in a residential section of the Town of Dyer, provided a good contrast to the other four green light signal installations. Although the configuration of the signal components is basically the same, the crossing is very smooth, requiring no slowing of vehicles to provide for a comfortable ride. Furthermore, this crossing was the most heavily travelled of the five. Each of two trains which were observed were travelling at an estimated 40-45 miles per hour and extinguished the green light for about one and one half minutes before train arrival and kept it extinguished for more than two and one half minutes after the train had cleared.

The vehicles approaching the crossing with the green light off reacted in like manner to those observed at the other crossings: vehicles slowed to complete or rolling stops and drivers looked in both directions for trains. Motorists approaching while the green light was on, however, in sharp contrast to those at the other four sites, proceeded through the crossing without slowing their vehicles or looking for trains, indicating a heavy reliance on the green light signal.



APPROACH A



APPROACH B

FIGURE 7. GREEN LIGHT SIGNAL INSTALLATION AT SITE 5: 213th STREET IN DYER, INDIANA

Summary Comments. Field inspection of these five installations and observation of more than 200 vehicles operating through them under both activated and non-activated conditions (compared to many similar observations at passively protected crossings), led to some impressions regarding their effect on motorists and possible improvements which might be made.

When the green light is in the off mode, it has the favorable effect on the motorist of prompting him to exercise more caution than he might at a crossing protected only by crossbucks. He appears to take more seriously his responsibility to look for an approaching train and to determine if it represents a hazard.

When the green light is on, however, driver reaction seems, to a great extent, to depend on the roughness of the crossing. If a crossing is so rough that a driver must slow his vehicle anyway, he will also look for approaching trains regardless of the presence of the green light. If, on the other hand, the crossing is smooth enough to traverse at normal speed without loss of comfort, he appears to rely on the signal to warn him of the approach of a train.

Several general improvements could be made to the green light signal installations at relatively low cost. These improvements would enhance the conspicuity and credibility of the signals, which would then command greater respect by the motoring public. The first and most obvious improvement

lies in better maintenance of the installations and trimming of vegetation to provide more adequate visibility of the signals, stop signs and crossbucks. The warning must be seen to be heeded. Modern reflectorized crossbucks would be helpful. Furthermore, enlarging the "WHEN LIGHT IS OUT" sign to about the size of the stop sign would make it more conspicuous.

At crossings where the system components are widely separated, a driver must look in several places before understanding his responsibility. That is, he must first see the crossbuck, then the stop sign and message, and then the green light. A decided improvement over this situation would be to mount a crossbuck, stop message, and green light all on one post for each approach. A compromise measure could be to at least install the stop message and green light together for each approach.

Although the brightness and aiming of the green lights appears to be generally good, a 12-inch rather than 8-inch lens may be better. Further, a black shield behind each light would provide it with better target value.

Finally, an inexpensive means of reducing the time of activation for the signal should be sought. The excessive warning times presently displayed, even for relatively fast trains, probably reduce the reliability of the signal for the motorist, since he is often being warned needlessly.

Proposed Active Devices at the Crossing

This section contains descriptions of several innovative protection devices which have been proposed and may hold promise for reducing the hazard of rail crossings to the motorist.

Arizona Cantilever Crossbuck and Flasher Sign

The Diagnostic Team for Railroad Crossings in Arizona has proposed installation and testing of the cantilever crossing signal shown in Figure 8. The reflectorized crossbuck, the same size as those used on standard flashing light signals, is superimposed on a black background. The "STOP WHEN FLASHING" sign will probably be removed, since flashing red lights mean "stop" by Arizona State Law. The red flashers will be either standard railroad flashers or standard 12-inch traffic signal heads. The entire device will be illuminated, illumination and flashers to be activated through track circuitry. In a comparison of prototypes of this signal, the 12-inch traffic signal heads were shown to be brighter and more eye-catching than the standard railroad signal heads, especially during daylight hours.

It is anticipated that this device might be useful both at presently unprotected crossings and at crossings already guarded by flashing lights but warranting additional protection. The cost of an installation of this sort, including pole, mast arm, sign and control system is estimated to be $7,000. A similar installation, utilizing

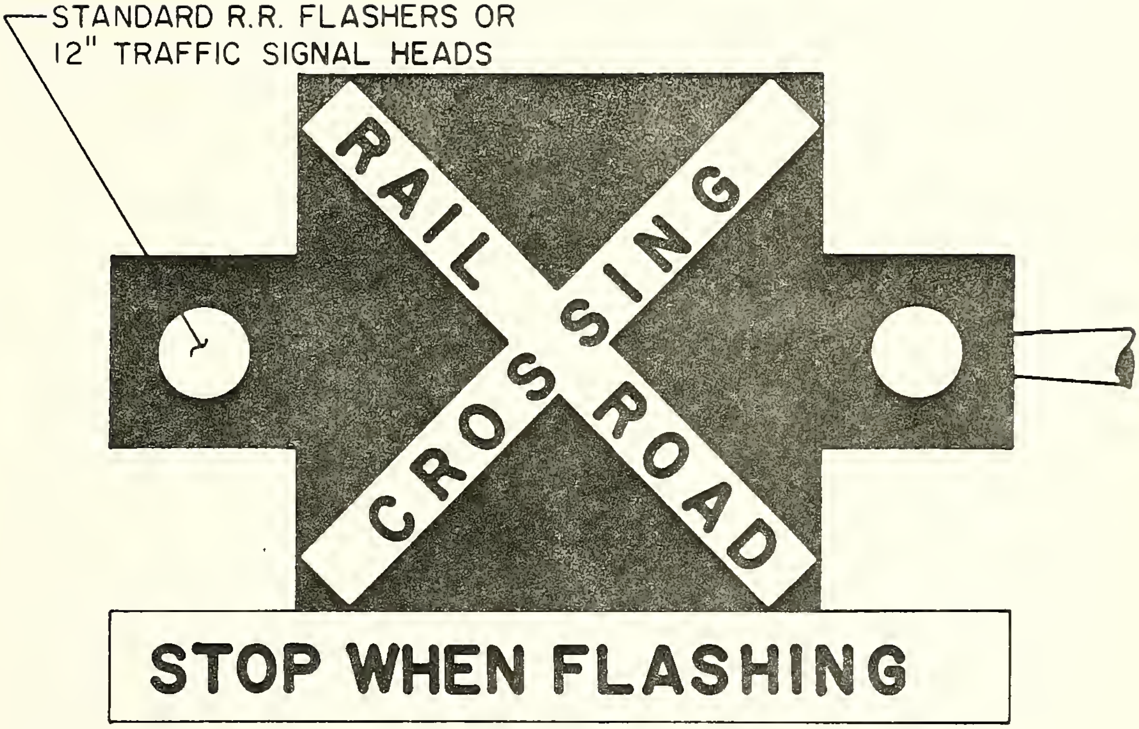


FIGURE 8. ARIZONA CANTILEVER CROSSBUCK AND FLASHER SIGN

existing railroad track circuitry, would cost approximately $4,800 (38).

Various Light-Related Information Sources for the Crossing

Several light-related crossing protection schemes for additional nighttime protection have been proposed in recent years. Although some are not "active" in the sense previously discussed, each promises a visual stimulus to the driver which is presently lacking.

The Voorhees report (60) pointed out that accidents involving highway vehicles striking passenger trains at night were by far less frequent than the same type accident involving freight trains. It appears that the reason for this is that the lighted windows of the passenger train provide the motorist with added train-presence information. It is further reported that approximately 93 percent of these freight train-car accidents involve the front one fourth of the train (60).

This brief discussion points to the need for illumination or reflectorization of the train and the crossing. The most obvious means for achieving this end is spot illumination of the train and crossing. This has been recommended by several researchers (50,60), especially where sight distance on the approach is bad. Such crossing illumination could be continuous or activated by the approach of a train.

Other means of providing train-presence information have been suggested, however. One recommendation is to provide flashing beacons, such as those used on emergency vehicles, on the locomotive (31,43,50,60). These flashing red lights, while commanding a great deal of respect, would be visible at great distances and would be a moving cue to the motorist. It is also anticipated that these flashing lights, or auxiliary lights from the locomotive, could effectively illuminate the passive protection signs at the crossing.

An illuminated panel along the length of the locomotive would serve much the same purpose as the flashing beacons in providing the visual stimulus of a moving train (60). A reflectorized panel on the locomotive, in lieu of flashing beacons or an illuminated panel, would, however, be effective only while it was across the highway, reflecting vehicle headlights back to the motorist.

Two other methods involving reflective signs have been proposed. The first is a reflectorized panel mounted on the opposite side of the tracks from an approaching car. A train traversing the crossing would then break the vehicle's headlight beam, producing a flashing effect and alerting the motorist to its presence (60). Another system would involve a sign which would catch the beam of a train headlight and reflect it down the highway, thus alerting drivers to the train's approach. It is noted that the design and

placement of the reflectors for both of these systems, so that the right amount of light is reflected in the right direction, is not a trivial matter (31,60).

Summary

This chapter has described many innovations in active grade crossing protection, both of the advance warning and "at the crossing" types. Some have been installed and observed to be effective; others have fallen short of the mark. Many more are still just ideas holding promise for safer grade crossings. While there is current traffic engineering emphasis on uniformity of signs, signals and markings, it is clear that sufficient latitude for the application of sound engineering judgment must be provided to allow for formulation and testing of new methods of providing safe, comfortable and efficient travel for the motoring public, especially in areas where deficiencies are apparent. Highway-railroad grade crossing protection is most certainly one of these areas.

CHAPTER III. VEHICLE SPEED PROFILES AT A HIGHWAY-RAILWAY GRADE CROSSING

As various improvements are implemented at hazardous grade crossing locations, there is great interest in knowing whether or not each improvement is successful in reaching its goal, namely the reduction of accidents. The ultimate "proof" of the value of any improvement will be the long-range accident history at the location. Since short-range accident rates are neither reliable nor predictable, valid conclusions cannot be drawn from short-range "before and after" studies. This is particularly true for a crossing which has a high number of accidents preceding a demanded improvement. The laws of probability declare that the expected number of accidents at such a location in a following period may be lower even if no improvement in the crossing protection is made. As many as 20 years of accident records may be required in order to draw valid conclusions from such data.

The study described in this chapter takes a different approach in evaluating the effect of safety improvements. A data collection system has been developed by which the speed profiles of vehicles approaching the crossing may be determined, thus indicating driver reaction to the grade crossing protective devices. Using this data collection technique,

data have been collected for a particularly hazardous rural crossing in Indiana which is protected by standard flashing light signals. It is expected that this information will serve as a base for comparison when similar data are obtained after each of several subsequent additions to the protection at this crossing.

The Site of the Research and the Improvement Program

The site of this research is the crossing of U.S. 31 and the Norfolk and Western (N & W) Railway in Tipton County, Indiana. The crossing is located approximately one mile north and five miles west of the City of Tipton, and one mile east of the Town of Goldsmith. The intersection of U.S. 31 and State Road 28, controlled by traffic light signals, is situated approximately one mile south of the crossing.

U.S. 31 in this vicinity is a concrete four-lane divided highway following a straight north-south orientation over level terrain. Lane width is 12 feet, the two approaches being divided by a 66-foot wide median. Narrow stabilized gravel shoulders are provided on each side of the roadway. The highway carries an average daily traffic (ADT) of approximately 10,000 vehicles. The posted speed limit is 65 miles per hour, while the 85th and 15th percentile speeds are 66 and 50, respectively.

The single main line track operated by the N & W across this highway is oriented in an east-west direction, thus

making a 90-degree crossing of highway and railway. There are no scheduled passenger trains over this track, and the freight trains, operated on an "as needed" basis, number about six per day. Train speed varies considerably in a range estimated from 20 to 60 miles per hour. The actual crossing is relatively smooth and can be traversed at high speeds with little or no loss of comfort.

County Road 100 S parallels the rail tracks on their southern edge. This is a narrow gravel-surfaced road carrying very light traffic. Its intersection with U.S. 31 is controlled by stop signs; yield signs are placed in the median between the U.S. 31 approaches.

Sight distance along the tracks for approaching highway traffic is very good, except in the southwestern quadrant where buildings and a small woods provide some slight obstruction to the view of eastbound trains for northbound motorists. This wooded area also presents a poor background contrast to train color for southbound motorists viewing an eastbound train. Visibility of trains is otherwise good, since the rail tracks are elevated slightly above the level of surrounding cultivated fields on both approaches.

The Crossing Protection

The crossing is protected by several sets of standard flashing light signals and reflectorized crossbucks. There are two such sets for each approach, one on either side of the travelled way. There are two additional sets of flashing

lights, one aimed down each approach of County Road 100 S. Since the variable train speeds are not taken into account by the signal activation hardware, times of activation vary considerably. Advance activation times of up to 90 seconds were observed for some particularly slow moving trains.

Standard round advance warning signs are placed in pairs, one on either side of each approach, at a distance of 1000 feet from the crossing on U.S. 31. During the period of data collection, one continuous yellow blinking light (typical barricade flasher) was in place on each advance warning sign. These lights were small and dim, thus not attracting much additional attention to the advance warning. Between the advance warning signs and the crossing, standard pavement markings are painted across both lanes of each approach. All signs, signals and markings were well maintained and in good repair. A schematic view of the crossing is given in Figure 9, and various photographic views are shown in Figures 10 through 12.

The Accident Record

Despite all of the favorable attributes of this crossing (i.e., level terrain, general good sight distance, active protection, and so on), the accident experience here has been extremely bad (34). Summaries of all accidents and of train involved accidents, both over a 15-1/2 year period, are presented in Tables 2 and 3, respectively. From these summaries it can be seen that the vast majority of

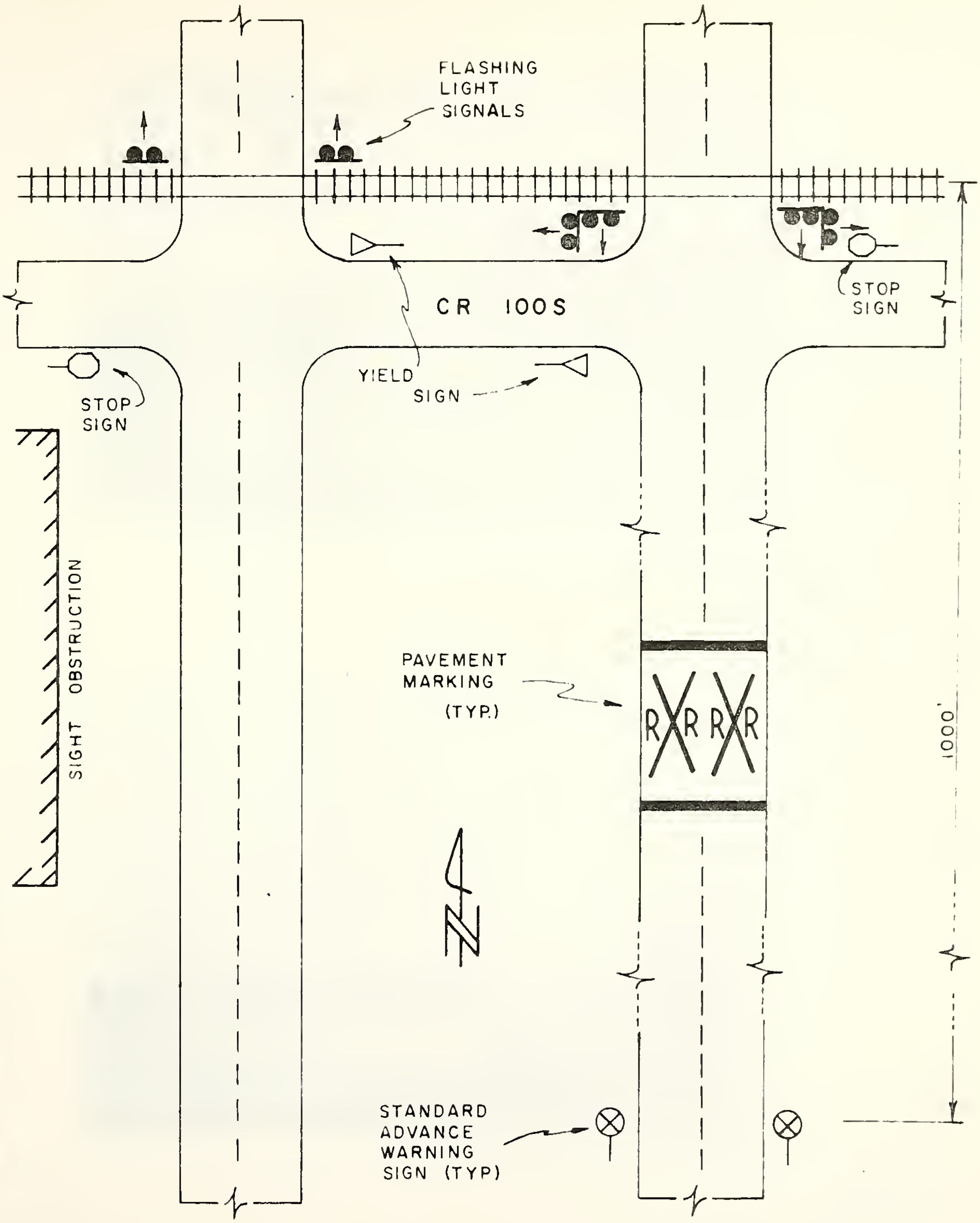


FIGURE 9. SCHEMATIC VIEW OF THE U.S. 31 – N&W RR GRADE CROSSING SITE NEAR TIPTON, INDIANA

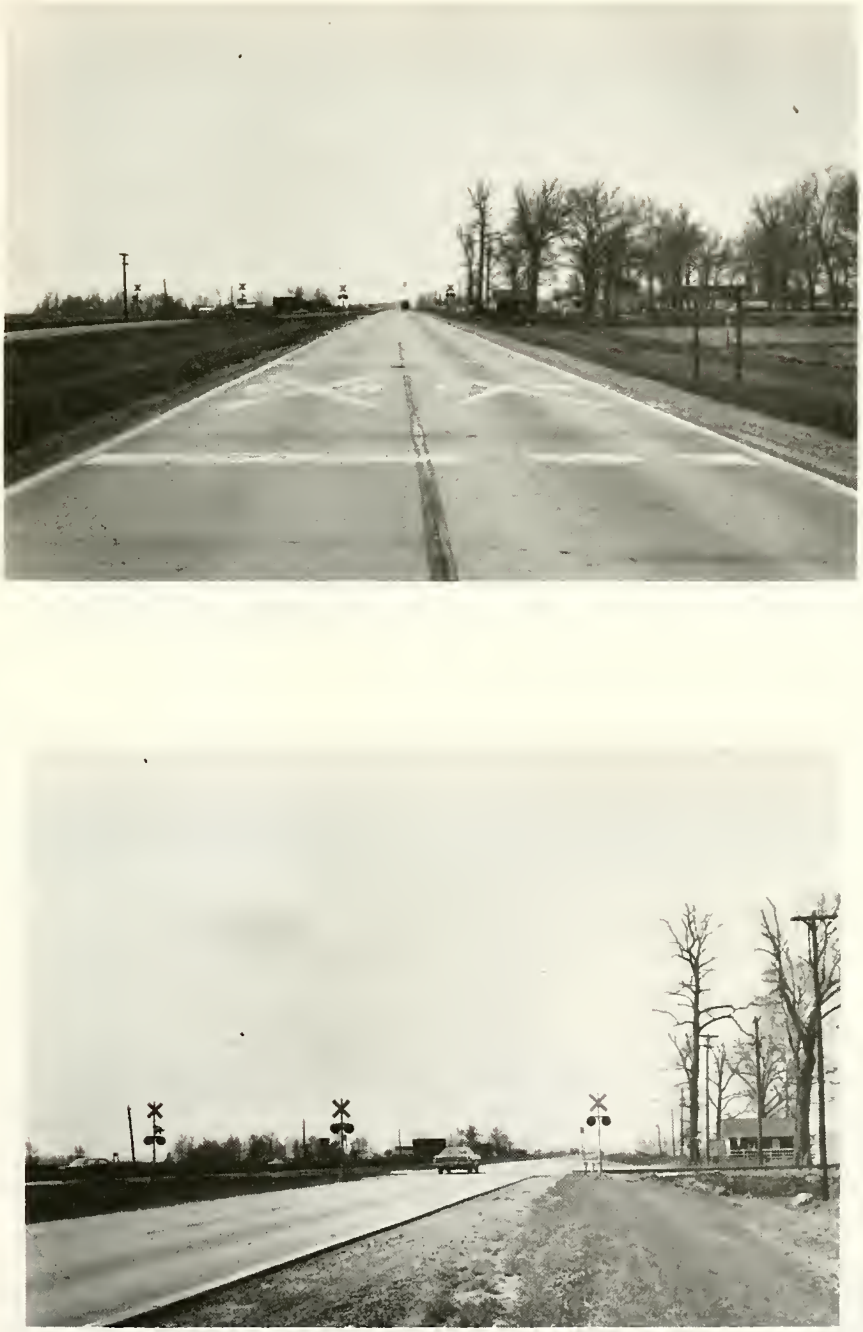
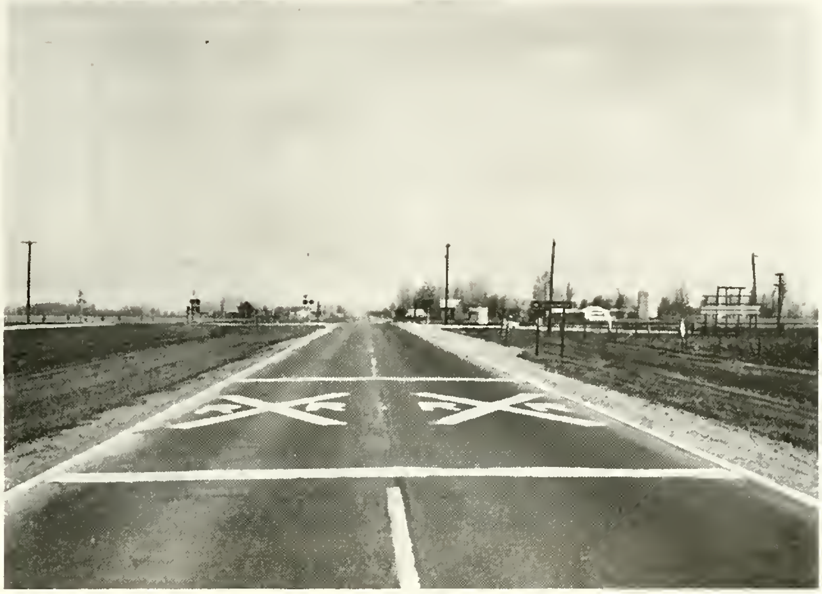


FIGURE 10. THE PROJECT SITE AS VIEWED FROM THE SOUTHBOUND LANES OF U.S. 31



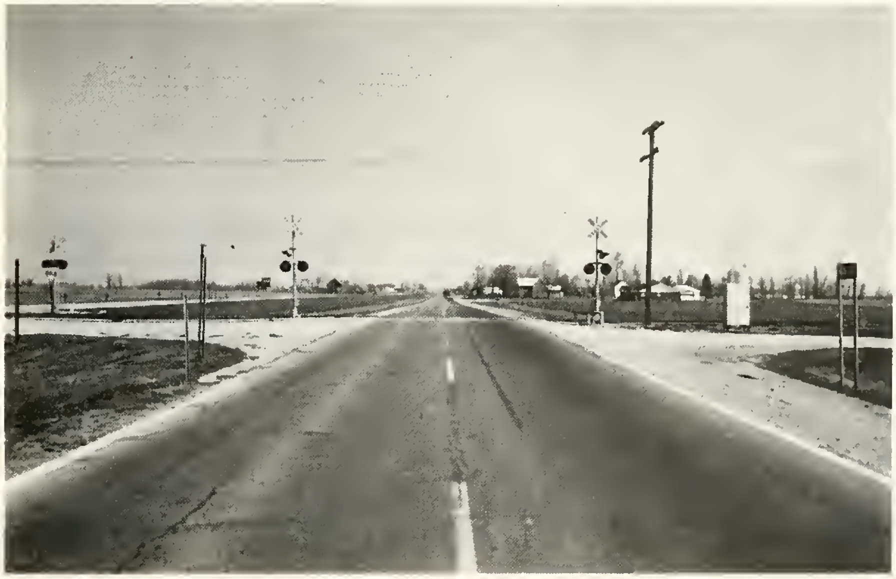
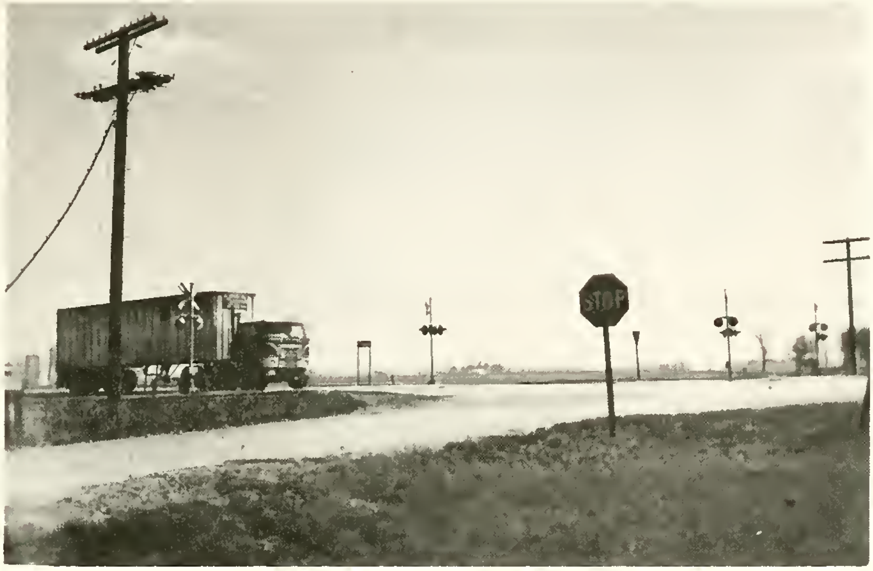
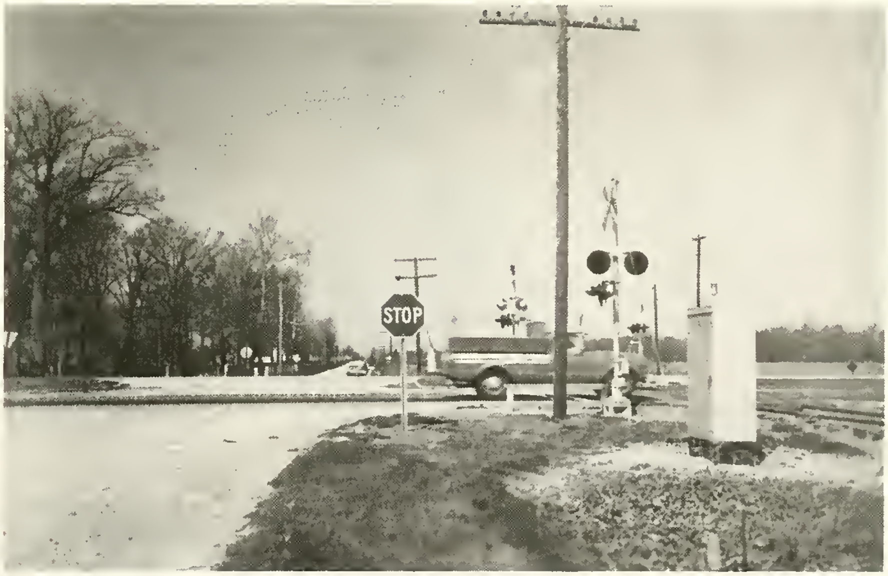


FIGURE 11. THE PROJECT SITE AS VIEWED FROM THE NORTHBOUND LANES OF U.S. 31



EASTBOUND



WESTBOUND

FIGURE 12. THE PROJECT SITE AS VIEWED FROM C.R. 100 S

Table 2. Summary of Accidents at the U.S. 31-N&W RR Crossing Site for the 15-1/2 Year Period, January 1, 1957 through July 1, 1972.

Accident Description:	Total Accidents	38
	Fatal Accidents	8
	Pers. Injury Accidents	14
	Prop. Damage Accidents	16
Casualties:	Total Fatalities	13
	Total Personal Injuries	26
Day of Occurrence:	Weekday	30
	Saturday or Sunday	8
Light Conditions:	Daylight	29
	Darkness	8
	Dawn/Dusk	1
Vehicle Direction:	Northbound	16
	Southbound	22
Pavement Condition:	Dry	31
	Wet	5
	Ice/Snow	2
Weather Condition:	Clear	34
	Raining	1
	Snowing	3
Type of Accident:	Rear End	17
	Right Angle	2
	Sideswipe	2
	Car Hit Train	7
	Train Hit Car	5
	Other	5
Train Involvement:	Train Present and Involved	12
	Train Present, Not Involved	12
	Train Not Present	14
Accidents Involving Movements From or Onto CR 100S, but Not the Crossing *per se*		4

Table 3. Summary of Train Involved Accidents at the U.S. 31 - N&W RR Crossing Site for the 15-1/2 Year Period, January 1, 1957 through July 1, 1972.

Date	Day of Week	Light Condition	Pavement Cond.	Weather Cond.	Train Speed,mph	Train Direction	Vehicle Speed mph	Vehicle Direction	Vehicle Struck Train	Train Struck Vehicle	No. Pers. Killed	No. Pers. Injured	Driver Age	Driver Sex
3/5/65	Fri.	Daylt.	Wet	Clear	45	EB	50	NB		XXX	1	0	65	M
4/16/65	Fri.	Daylt.	Dry	Clear	58	EB	?	NB		XXX	1	1	61	M
9/28/65	Tue.	Daylt.	Dry	Clear	60	EB	60	NB	XXX		2	0	53	M
12/24/66	Sat.	Daylt.	Dry	Clear	40	EB	60	SB	XXX		0	1	76	M
12/25/66	Sun.	Daylt.	Dry	Clear	40	WB	55	SB	XXX		0	1	55	M
5/25/66	Sat.	Darkns	Dry	Clear	60	WB	60	SB	XXX		1	1	22	M
1/24/69	Fri.	Daylt.	Wet	Snow	60	EB	65	SB		XXX	0	0	39	M
3/6/70	Fri.	Daylt.	Dry	Clear	53	EB	75	SB	XXX		0	1	47	M
2/12/71	Fri.	Daylt.	Ice	Rain	?	?	?	SB	XXX		0	1	46	F
9/5/71	Sun.	Daylt.	Dry	Clear	54	EB	60	SB	XXX		4	0	73	M
10/13/71	Wed.	Daylt.	Dry	Clear	50	WB	?	SB		XXX	1	0	80	M
10/29/71	Fri.	Daylt.	Dry	Clear	51	WB	65	SB		XXX	2	0	71	M

the 38 total accidents at this location have occurred during daylight hours on weekdays under clear skies with accompanying dry pavement. The accidents were nearly evenly divided between those taking place when a train was present and involved, was present but not involved, and was not even present. (This further reinforces the distribution of grade crossing accidents discussed in Chapter I.)

In total, there have been eight fatal accidents and 14 personal injury accidents resulting in 13 deaths and 26 injuries. All of the fatalities have occurred since March, 1965, and all but one have resulted from one of the 12 train-car collisions. The majority of train-car crashes involved male drivers over 45 years of age, driving on the southbound approach (where the sight distance is best). The accident experience has grown progressively worse, reaching a peak of seven fatalities in 1971.

The Improvement Program

This baffling accident experience was of great concern to the Indiana State Highway Commission (ISHC). In an effort to improve the safety aspects of this very hazardous crossing, a series of three emergency additions to the crossing protection were planned. The three additions were:

1. Overhead red flashers, two over each approach, on cantilever arms;
2. Overhead illumination of the crossing;
3. Automatic crossing gates.

Each of these improvements was to be added to the existing signals and any previous addition, and to be activated simultaneously with the flashing light signals through existing track circuitry. Realizing there would be no guarantee that these improvements would be effective, a means was sought to analyze the effect of each addition on driver reaction. Since the additions to the standard flashing lights were to be made in fairly rapid succession (at approximately one month intervals), it was not practical to wait long enough to collect statistically valid accident data. Short-range analytical methods were to be used to evaluate driver performance in each of the four phases of the project. These four phases were to be:

Phase I:	Under existing flashing light signal control;
Phase II:	After cantilevered red flashers were installed (but before the crossing illumination);
Phase III:	After the crossing illumination was installed (but before the crossing gates);
Phase IV:	After automatic crossing gates were installed.

Due to extended negotiations between the ISHC and the N & W Railway as to the acceptance of liability under the experimental protection schemes, the first improvement was delayed for several months and at this writing has not yet

been implemented. For this reason, data have so far been collected only for Phase I of the project, with data for the remaining phases to be collected and analyzed when the subsequent improvements are made. When all of the data are finally obtained on each improvement, the relative effect and value of each improvement will be determined; i.e., does a certain addition cause average and all drivers to reduce speed significantly at a greater distance from the crossing. The analysis of the Phase I data is presented later in this chapter.

It should be kept in mind that the data collection system described in the next section was developed under the assumption that the improvement program would be carried out on schedule, thus placing serious constraints on the time and level of sophistication available for the development of the system.

The Data Needed and the Data Collection System

The data required to effectively determine driver reaction in the vicinity of the crossing were sufficient spot speeds of individual vehicles to develop the speed profiles of these vehicles for the length of the affected approach. It was anticipated that several pieces of information could be obtained from these speed profiles. The vehicle's rate of deceleration could be calculated and classified as comfortable, sudden, skidded and so on. The point along the approach where the driver first took corrective action to

allow for the conditions at the crossing could also be determined.

Constraints on the Data Collection System

Several constraints were imposed on the development of the data collection system. The first was time; the system had to be implemented and data collection begun at the earliest possible date. A financial constraint also existed in that large sums of money were not available for equipment or for operation of the system. The equipment to be used had to be either on-hand or readily available at nominal cost. Finally, all data would have to be collected without the drivers' knowledge, a requirement which would necessitate the effective hiding of all personnel and equipment.

Development of the System

Two data collection techniques were first considered, but rejected as violating one or more of the above requirements. First, the use of radar meters was proposed. Since radar meters must be placed fairly close to the roadway when in use, it was determined that they could not be effectively hidden at this site. A sufficient number of meters was not readily available, and other operational difficulties were also foreseen.

Next, a system was considered which utilized pairs of induction loops inbedded in the pavement. Each pair of loops would constitute one speed trap. The impulse caused

by the passage of a vehicle over each induction loop would be recorded on a central recording unit (a 20-pen recorder) and would later be correlated so that the required spot speeds for each vehicle could be determined. Although the cost of installing induction loops is not high, the time required to implement this system would have been too long. Therefore, this system was also abandoned.

The implemented data collection system employed a photographic process, following a technique similar to one previously used by Tharp (54). A camera setup position was determined for each approach. For the northbound approach, this position was in the southeast quadrant of the crossing; for the southbound approach it was in the northwest quadrant. Each of these camera setup positions was located at a distance of approximately 750 feet from the roadway and 600 feet from the rail tracks. Permission to occupy these positions was secured from the affected property owners.

Markers were then placed radially from each setup position along the highway right-of-way line, which parallels the roadway at a distance of 36 feet. These markers were placed in pairs such that each pair intersected a 55-foot length of roadway with a 100-foot interval between the end of one trap and the beginning of the next. A schematic view of marker placement and camera setup position is shown in Figure 13. The average speed of a vehicle over the 55-foot trap was assumed to approximate the spot speed at the

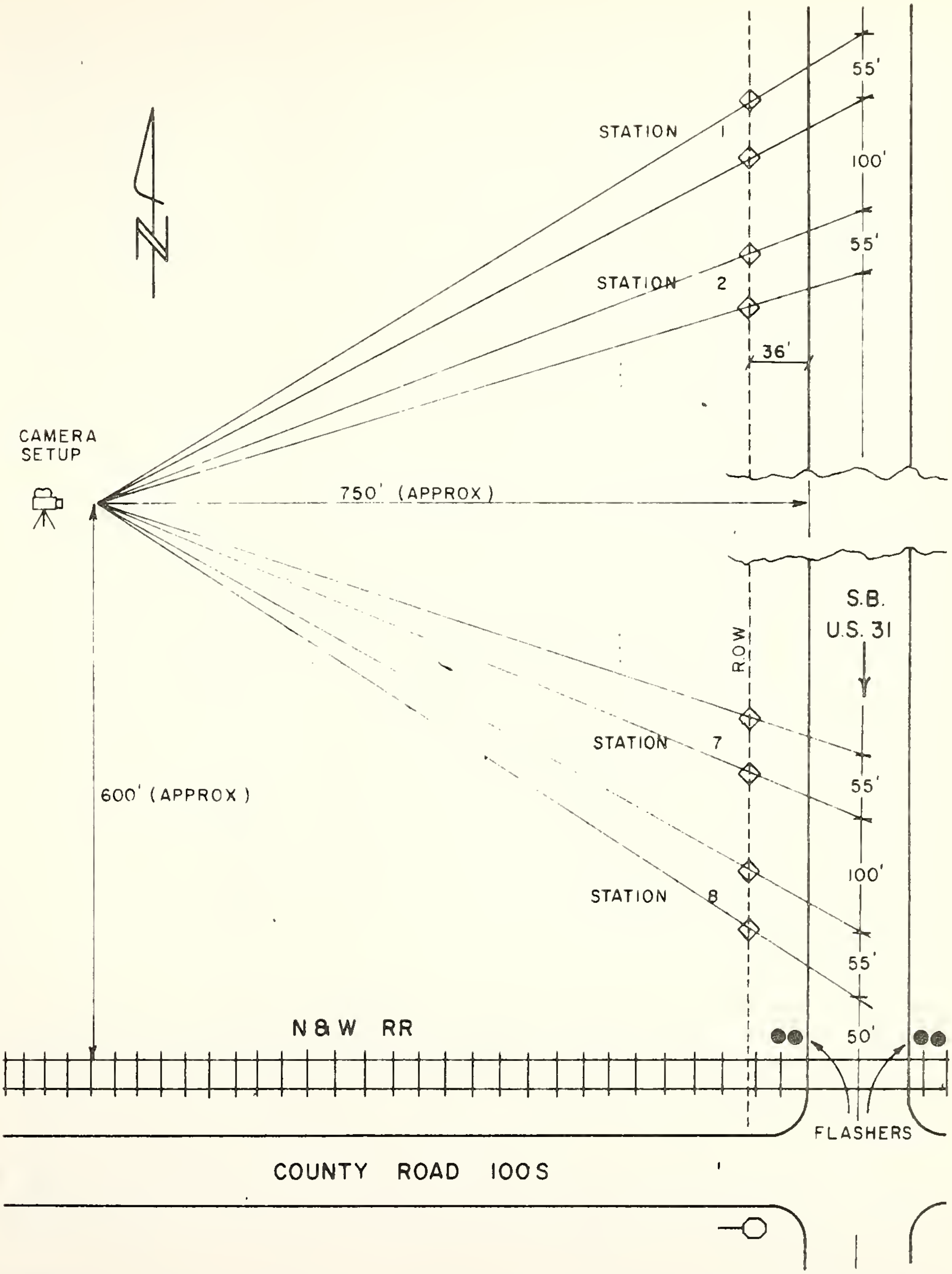


FIGURE 13. SCHEMATIC, VIEW OF MARKER PLACEMENT AND CAMERA SETUP POSITION (TYPICAL)

center of the trap. Therefore, spot speeds could be obtained for each vehicle at eight equally spaced stations. The station designations were as given in Table 4.

A close-up view of a typical marker is shown in Figure 14. Each marker was a 2-foot by 2-foot square of sheet metal supported in a diamond configuration on a steel post. The markers were placed at a height so as to be silhouetted against passing vehicles when viewed from the observation point.

Table 4. Numbers and Locations for the Eight Spot Speed Stations on Each Approach.

Station Number	Distance from Nearest Track (feet)
1	1162.5
2	1007.5
3	852.5
4	697.5
5	542.5
6	387.5
7	232.5
8	77.5

Markers were painted white on the side facing the camera and green on the side facing the highway. The supporting posts were also painted green. This was in an effort to make the markers as inconspicuous as possible to passing motorists. Since the camera setup position was at such a great distance from the roadway, no special camouflage was deemed necessary for the observer.

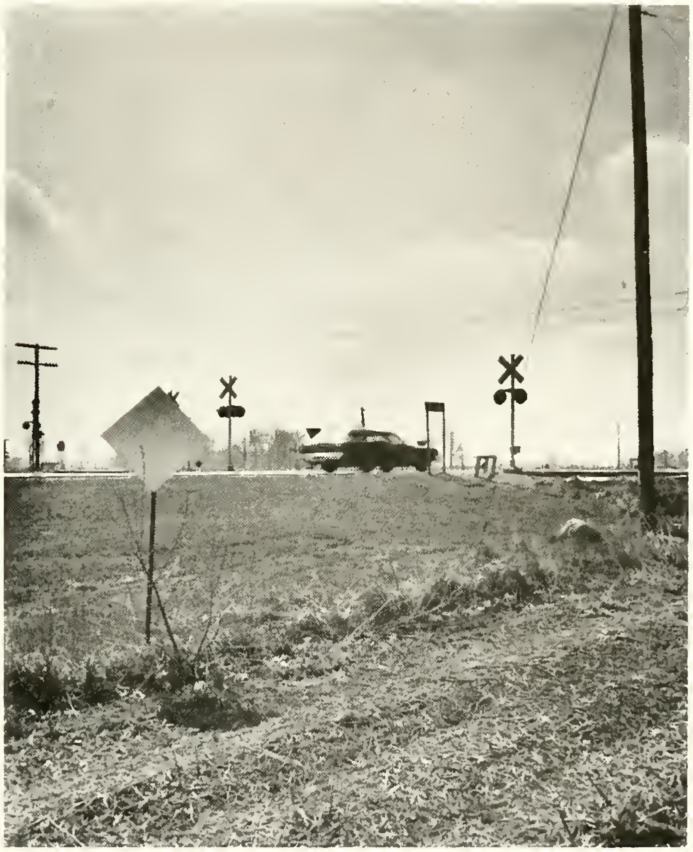


FIGURE 14. A TYPICAL MARKER IN PLACE AT THE SITE

The photographic equipment used in this research was leased from the Audio-Visual Department at Purdue University. Film purchasing and all developing of exposed film were also handled through this department. The camera used was a 16-mm Ariflex-M motion picture camera. This camera is powered by an eight volt rechargeable battery and has the capacity for 400-foot film magazines; thus film wastage was minimized. A 12-120-mm Augeneux zoom lens was used with the camera in order to provide good close-up views of vehicles over the required distances. The camera is driven by a variable-speed electric motor and is equipped with a tachometer calibrated in frames per second, so that film speed may be checked and kept constant. After an initial check on film speed was run by photographing a stop watch, the speed indicated on the tachometer was assumed accurate throughout the remainder of the study. All movies were taken at a film speed of 24 frames per second.

Data Reduction

After the films were developed they were viewed with the use of an Industrialist Stop-Motion Projector (modified from a Kodak Analyst Projector). Each subject vehicle was followed through each of the eight speed traps. The number of movie frames it took the vehicle to traverse between the two markers constituting a trap was recorded to the nearest one-third of a frame. This number of frames was subsequently converted to miles per hour by the formula:

$$\text{mph} = \frac{(24 \text{ frames/sec})(3600 \text{ sec/hr})(55 \text{ feet})}{(5280 \text{ feet/mile})(\text{number of frames})} ;$$

which reduces to:

$$\text{mph} = \frac{900}{\text{number of frames}}$$

An error of one-third of a frame in estimating the total number of frames would result in an error of less than one mile per hour for speeds lower than 50 miles per hour and a slightly larger error for speeds over 50. A computer program was prepared to convert the number of frames into speed for each vehicle for each of the eight speed traps.

Shortcomings of the System

Although the data collection system met all functional requirements and operated well, some shortcomings became apparent during the course of the study. The first of these was the nonproductive time involved in daily setups. Early in the morning of each day of data collection, the Chief Dispatcher of the N & W Railroad was telephoned in order to obtain a daily train schedule. Since the trains did not run on a regular schedule, but rather on an "as needed" basis, the estimates given by the dispatcher were seldom correct, even as to the total number of trains passing this point. Therefore, the usual procedure was to go to the site as early as possible and wait for the trains as they approached. Travel time to the site was about one hour, and

equipment setup and takedown added another half-hour, thus totaling about two and one-half hours per day. Data could be collected only on one approach at a time, with much of the day being idle time. Furthermore, most of the data were collected in early spring when temperatures were still quite cool, and the observer had little protection from the elements during the daily activity. On several occasions when a train did approach, no highway vehicles happened to be approaching at the same time. Several train passages occurred, therefore, with no data being collected.

All of this points to the desirability of developing an inexpensive automatic data collection system, perhaps activated through train presence, which would be more efficient than the system which was used in this study.

Another point of concern was the inability of the system to collect data during hours of darkness. Night data will be desirable since it was anticipated that the crossing illumination phase would have its greatest impact during hours of darkness. Attempts were made to adapt the system by illuminating the markers and using more sensitive film in order to pick up these lights and the lights of passing vehicles. This proved to be unacceptable because older model cars, not equipped with front and rear "running lights," did not show up in the films after passing the midpoint of the approach. It was suggested, however, that the use of radar meters might be acceptable at night, since the darkness would provide much of the camouflage required to hide

them effectively.

Despite these noted deficiencies, the data collection and reduction techniques described in this section provided a relatively inexpensive and quickly implemented system which was used effectively to collect the required data as described in the following section.

Phase I Data

All data were collected during daylight hours, under conditions of clear visibility and dry pavement. In order to minimize the influence of stimuli other than the prevailing conditions at the crossing, a vehicle was sampled only if there were no other moving vehicles between it and the crossing as it entered Station 1. Thus a driver was allowed to choose his own speed through the approach.

Vehicle Categories

Throughout the study, the data from each approach were kept separate, since the conditions on the approaches differ. There were four basic categories of vehicles which were sampled for each approach. The drivers in each successive category were presented with one added visual stimulus at the crossing.

The first category was that of "free flow vehicles." The motorists in this category travelled through the approach with no stimulus other than the existence of the crossing and its unactivated protection devices. No trains were

present.

The second category consisted of vehicles which entered at the first station while the flashers were activated by an approaching train, but chose to pass through the crossing. They were not obstructed from passing through by other vehicles or by the close proximity of the train. The added stimulus was that of the activated flashers. This category was designated as "first unobstructed vehicles."

The third category of interest was "first obstructed vehicles." These were vehicles entering the first station when the flashers were activated and a train was already across the road, or was in such close proximity as to present an immediate hazard. These vehicles were thus obstructed from passing through the crossing by the added stimulus of train presence.

The final vehicle class was called "following vehicles." These vehicles entered the first speed trap under conditions of signal activation, a train across the roadway, and the added condition of at least one vehicle already stopped at the crossing waiting for the train.

The limited truck volume on this highway did not allow an ample number of trucks to be sampled in each category. Free flow trucks were sampled, however. The total number of observations obtained for each category is presented in Table 5.

Table 5. Number of Observations Obtained in Each Vehicle Category.

Category	Northbound	Southbound
Free Flow Trucks	79	46
Free Flow Cars	144	143
First Unobstructed Cars	15	15
First Obstructed Cars	10	10
Following Cars	25	33
Totals	273	247
Overall Total	520	

Methods of Comparison

Because it was not possible to collect data for any phases of crossing protection improvement, as discussed previously, means were sought to compare driver performance in each of the four vehicle categories for Phase I. A logical basis for this comparison was thought to be the rate of deceleration exhibited by a vehicle approaching the crossing, a high rate indicating severe braking of the vehicle due to delayed reaction by the driver. The Traffic Engineering Handbook (6) describes several rates of deceleration as follows:

> Deceleration of above 20 ft per sec per sec will be used only in emergency situations. At decelerations above this value, the occupants must brace themselves firmly to avoid being thrown off the seat. At decelerations of 14 ft per sec per sec, packages may

> slide off the seat, and the occupants of the vehicle find this rate uncomfortable. A deceleration rate of 11 ft per sec per sec is considered undesirable but not alarming to passengers.
>
> Practical values of deceleration used in every day traffic conditions rarely exceed 8 to 9 ft per sec per sec.

Following these guidelines, classes of deceleration were established for this study, a higher number indicating more severe deceleration. The classes were: Class 1) eight ft per sec per sec or less--comfortable; Class 2) above eight and through eleven ft per sec per sec--undesirable; Class 3) above eleven and through fourteen ft per sec per sec--uncomfortable; Class 4) above fourteen and through twenty ft per sec per sec--very uncomfortable; Class 5) above twenty ft per sec per sec--emergency.

Seven deceleration rates were calculated for each of the 520 observed vehicles; i.e., one deceleration rate between each of the eight stations for each vehicle. These rates were calculated according to the formula (6):

$$v_f = v_o - \sqrt{2dl}$$

where: v_f = final velocity in feet per sec

v_o = initial velocity in feet per sec

d = deceleration rate in feet per sec per sec

l = distance in feet

Applying the necessary conversion factors and a value for l of 155 feet (the distance between stations), this formula converts to:

$$d = \frac{V_o^2 - V_f^2}{144.19}$$

were: d = deceleration rate in feet per sec per sec

V_o = initial velocity in miles per hour

V_f = final velocity in miles per hour

Of the 3640 deceleration rates calculated and classified (520 vehicles times seven rates per vehicle), a surprisingly few were higher than comfortable. Only one rate fell into Class 4, two in Class 3, 17 in Class 2, and the remainder in Class 1. No Class 5 rates were noted. Exact values of deceleration within a class were not of interest; the matter of concern was whether a vehicle was slowing at a comfortable rate or whether that rate was more drastic. Vehicles in all categories almost unanimously slowed comfortably where necessary, throughout the approach.

Driver performance was also compared by other methods, reflected in the several tables and graphs to follow. First, a 10 mile per hour pace was established for each vehicle category. This 10 mile per hour pace, described as "the 10 mph speed range containing the largest percentage of vehicles in a sample of spot speeds" (6), was calculated for the entry speed (i.e., the speed at Station 1) in each category. In all cases, the eight mean spot speeds of the vehicles in the pace were nearly identical to the means for all of the vehicles in that category. Therefore, the overall mean was used for comparison. (Free flow categories are also reported as in pace, above pace and below pace vehicles.)

In Table 6 the overall mean spot speeds at each of the eight stations are presented for free flow cars and trucks on both approaches. Each mean spot speed is also represented as a percentage of the entry mean speed. These means are presented graphically in Figure 15. It can be seen that in general vehicles approaching under free flow conditions decelerate very slightly before the crossing, probably in anticipation of crossing roughness.

In order to determine differences in operating characteristics between the two approaches, statistical tests were performed on the differences in mean entry speeds for the various free flow vehicle categories. These tests, all run at the 5 percent level of significance, are given in Table 7. When comparing each pair of mean entry speeds, an F-test was run on the difference in the variances of these means. In testing variances, a two-sided F-test was performed with the null hypothesis being that the variances for the groups were equal, and the alternate hypothesis that they were not equal. The null hypothesis was not rejected in any of the tests, indicating homogeneity of variances for each pair and allowing standard t-tests to be run on the differences between the means.

An alternate method for making comparisons among the means is one developed by Scheffé. The probability of rejecting the hypothesis of equal means when, in fact, it should be accepted, is higher using the repeated t-test than when using Scheffé's test. For this study, however, a major concern was to identify factors which might influence the

TABLE 6. SPEED LOCATION AND PER CENT OF ENTRY SPEED CHART FOR NORTHBOUND AND SOUTHBOUND FREE FLOW CARS AND TRUCKS

	LOCATION BY STATION NUMBER							
	1	2	3	4	5	6	7	8
OVERALL MEAN OF S.B. FREE FLOW CARS, N=143	68.4	68.3	68.2	68.6	67.6	67.1	66.9	66.3
	100.0	100.0	99.7	100.3	98.8	98.1	97.8	96.9
OVERALL MEAN OF N.B. FREE FLOW CARS, N=144	65.6	65.7	66.2	66.1	66.1	65.4	63.9	62.8
	100.0	100.2	100.9	100.8	100.8	99.7	97.4	95.7
OVERALL MEAN OF S.B. FREE FLOW TRUCKS, N=46	58.0	57.7	57.4	57.5	56.4	55.8	55.4	54.9
	100.0	99.5	99.0	99.1	97.2	96.2	95.5	94.6
OVERALL MEAN OF N.B. FREE FLOW TRUCKS, N=79	53.4	53.4	54.0	54.1	54.1	53.7	52.5	51.4
	100.0	100.0	101.1	101.3	101.3	100.6	98.3	96.2

MEAN SPEED, MPH
% OF ENTRY SPEED

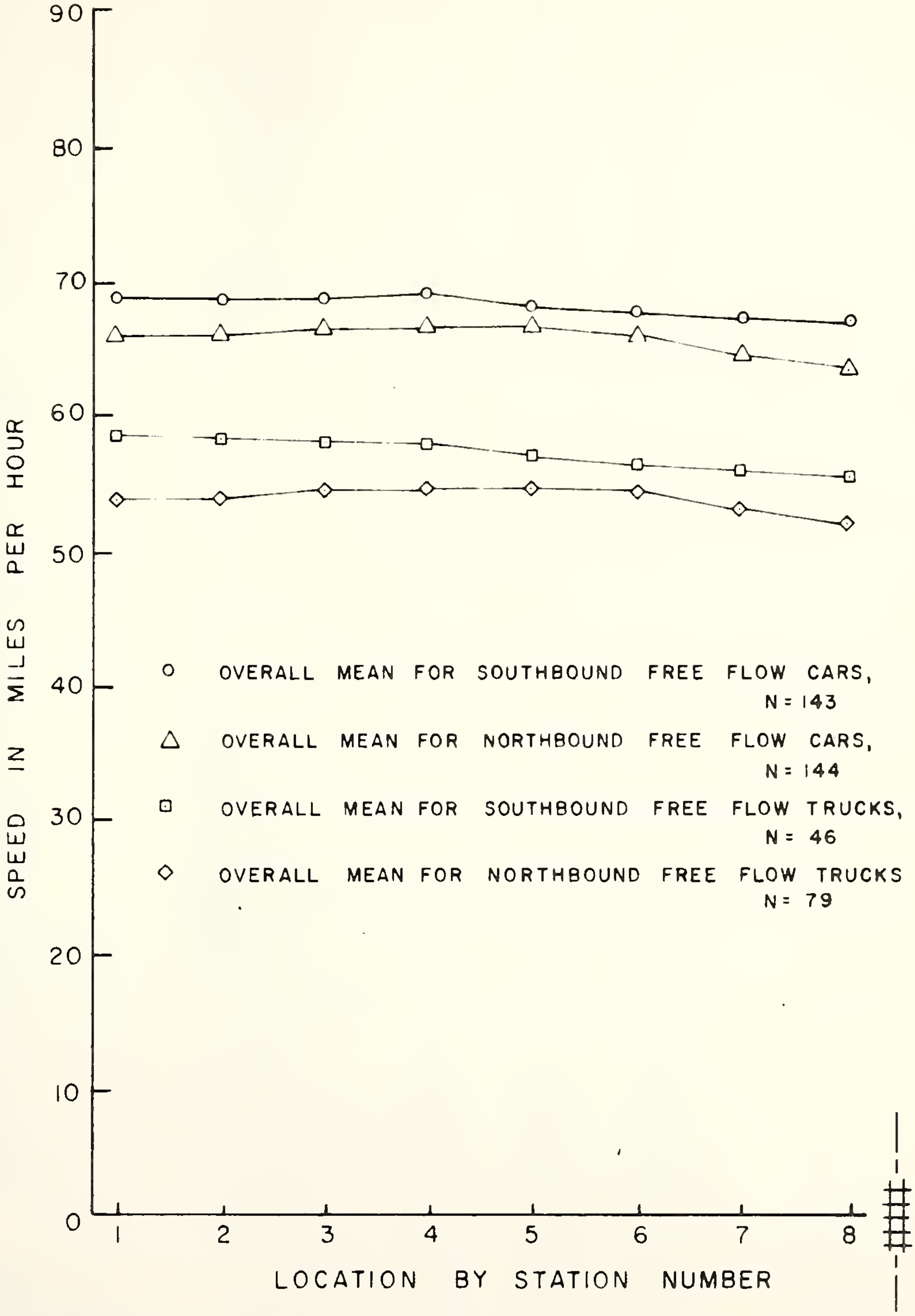


FIGURE 15. SPEED LOCATION GRAPH FOR NORTHBOUND AND SOUTHBOUND FREE FLOW CARS AND TRUCKS

TABLE 7. TESTS ON DIFFERENCES BETWEEN MEAN ENTRY SPEEDS FOR ALL FREE FLOW VEHICLES ($\alpha = .05$)

VEHICLE CLASSIFICATION	n	MEAN ENTRY SPEED	STANDARD DEVIATION S	VARIANCE S^2	$H_0: \sigma_1^2 = \sigma_2^2$; $H_1: \sigma_1^2 \neq \sigma_2^2$			$H_0: \mu_1 = \mu_2$; $H_1: \mu_1 > \mu_2$		
					F_{CALC}	F_{CRIT}	RESULT	t_{CALC}	t_{CRIT}	RESULT
1 - S.B. FREE FLOW CARS	143	68.4	6.3	39.7	1.202	1.34	DO NOT REJECT	3.558	1.651	REJECT
2 - N.B. FREE FLOW CARS	144	65.6	6.9	47.6						
1 - S.B. FREE FLOW TRUCKS	46	58.0	6.6	43.6	1.162	1.24	DO NOT REJECT	3.623	1.659	REJECT
2 - N.B. FREE FLOW TRUCKS	79	53.4	7.1	50.4						
1 - S.B. FREE FLOW CARS	143	68.4	6.3	39.7	1.078	1.52	DO NOT REJECT	9.625	1.654	REJECT
2 - S.B. FREE FLOW TRUCKS	46	58.0	6.6	43.6						
1 - N.B. FREE FLOW CARS	144	65.6	6.9	47.6	1.042	1.42	DO NOT REJECT	12.536	1.652	REJECT
2 - N.B. FREE FLOW TRUCKS	79	53.4	7.1	50.4						

actions of drivers in the vicinity of the crossing. One of these factors may be the vehicle entry speed. It was considered more desirable to reject the hypothesis of equal means when it should not be rejected, than to accept the hypothesis when it should not be accepted. Therefore, the repeated t-test was performed in preference to Scheffé's test.

One-sided tests were performed on the mean entry speeds, with the null hypothesis stating that the means were equal and the alternate hypothesis stating that one mean was larger than the other. The results of these tests, indicate that, for each approach, free flow cars enter the approach significantly faster than do free flow trucks. It can also be stated that southbound free flow cars and trucks approach at significantly greater speeds than do their counterparts in the northbound lanes. This phenomenon may possibly be attributed to a combination of two situations peculiar to the northbound approach. First, all northbound vehicles had just passed through the signal controlled intersection of U.S. 31 and S.R. 28 approximately one mile south of the railroad crossing. The travel speeds of these vehicles, especially trucks, may not have leveled off before reaching the crossing. Second, sight distance to the east is restricted for northbound vehicles, as discussed earlier, so a bit more caution may have been exercised by these drivers.

Further exploring the characteristics of free flow vehicles at the crossing approach, each group of free flow vehicles is separated into pace, above pace and below pace vehicles. Tabular and graphical representation of mean spot

speeds for each group are depicted in Tables 8 through 11 and Figures 16 through 19. Again, the general tendency toward slight deceleration before the crossing prevails, even when divided into these smaller groups.

Table 12 and Figure 20, following the established format, compare the overall mean spot speeds for each of the four categories of southbound cars. Since the entry speeds for the four categories appeared to differ greatly, tests were again performed to determine if these differences were significant. These tests are shown in Table 13. Two-sided F-tests were performed on the variances, and one-sided t-tests on the mean entry speeds. Where the F-test indicated that variances could not be assumed equal, the t-test was run according to an approximate procedure recommended by Ostle (46). The following conclusions may be drawn from the results of these tests on southbound cars: (1) free flow cars enter the approach at about the same speed as first unobstructed cars, but faster than first obstructed and following cars; (2) entry speeds of first unobstructed cars may not be distinguished from those of first obstructed cars, but are faster than those of following cars; (3) entry speeds for first obstructed cars are faster than those of following cars.

Spot speeds for each separate category of southbound cars were investigated next. In each case the overall averages for free flow vehicles are presented for the sake of comparison, along with the overall average for the category in question, the vehicle with the fastest entry speed, the

TABLE 8. SPEED LOCATION AND PER CENT OF ENTRY SPEED CHART FOR SOUTHBOUND FREE FLOW CARS

	LOCATION BY STATION NUMBER							
	1	2	3	4	5	6	7	8
OVERALL MEAN, N=143	68.4	68.3	68.2	68.6	67.6	67.1	66.9	66.3
	100.0	100.0	99.7	100.3	98.8	98.1	97.8	96.9
MEAN OF PACE VEHS, N=100 (PACE = 63–73, % = 69.9)	67.9	67.8	67.7	68.3	67.4	67.0	66.8	66.1
	100.0	99.8	99.7	100.6	99.3	98.7	98.4	97.3
MEAN OF ABOVE PACE VEHS, N = 25	78.0	77.9	77.9	78.3	77.0	76.2	75.7	75.4
	100.0	99.9	99.9	100.4	98.7	97.7	97.1	96.7
MEAN OF BELOW PACE VEHS, N=18	57.8	57.7	56.9	57.3	56.1	55.2	55.0	54.8
	100.0	99.8	98.4	99.1	97.1	95.5	95.2	94.8

MEAN SPEED, MPH
% OF ENTRY SPEED

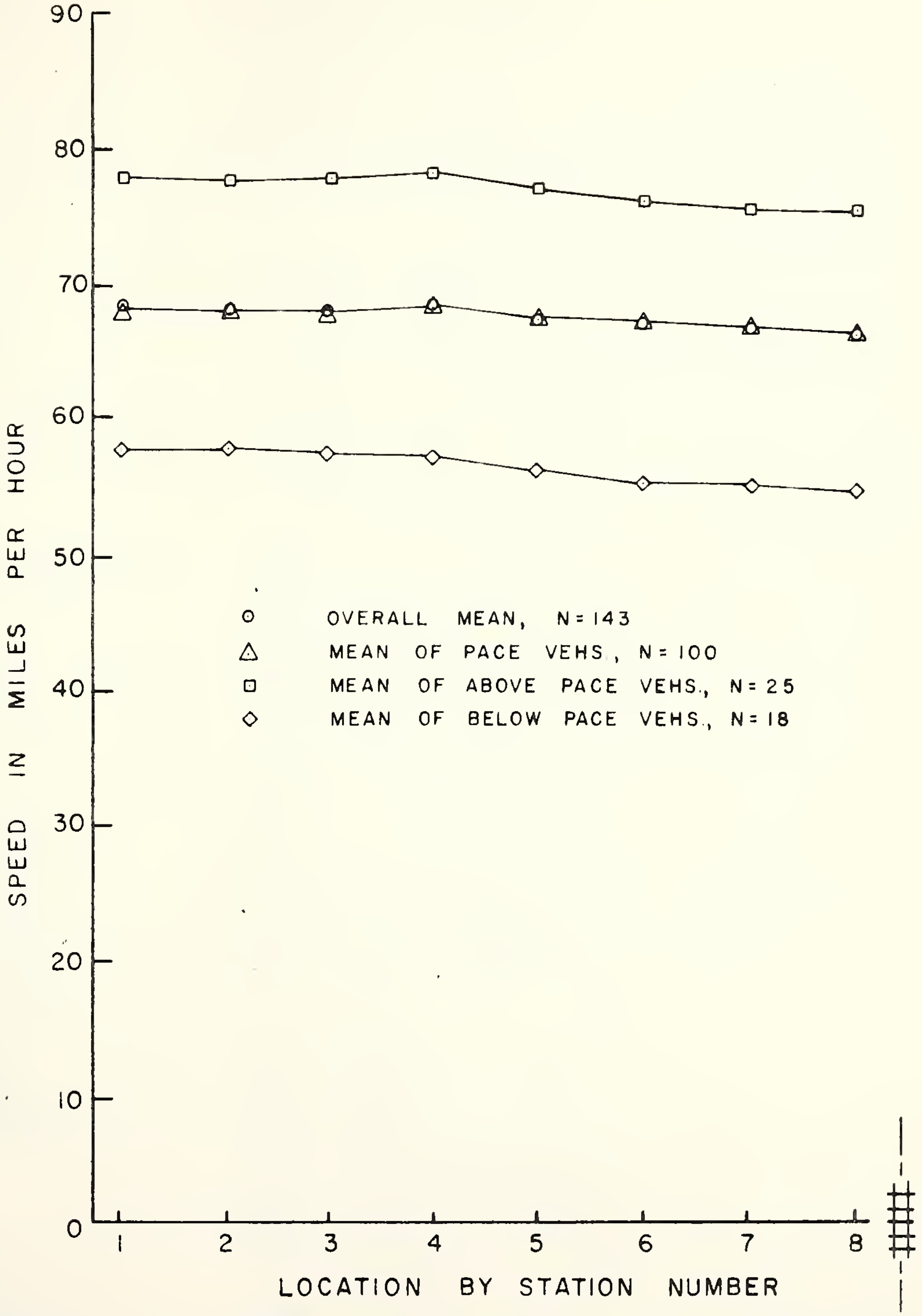


FIGURE 16. SPEED LOCATION GRAPH FOR SOUTHBOUND FREE FLOW CARS

TABLE 9. SPEED LOCATION AND PER CENT OF ENTRY SPEED CHART FOR NORTHBOUND FREE FLOW CARS

	LOCATION BY STATION NUMBER							
	1	2	3	4	5	6	7	8
OVERALL MEAN, N=144	65.6	65.7	66.2	66.1	66.1	65.4	63.9	62.8
	100.0	100.2	100.9	100.8	100.8	99.7	97.4	95.7
MEAN OF PACE VEHS, N=92 (PACE = 59 – 69, % = 63.8)	64.7	64.7	65.3	65.2	65.2	64.3	62.9	61.9
	100.0	100.0	100.9	100.8	100.8	99.4	97.2	95.7
MEAN OF ABOVE PACE VEHS, N= 32	75.0	75.0	75.3	75.3	75.0	74.4	72.5	71.5
	100.0	100.0	100.4	100.4	100.0	99.2	96.7	95.3
MEAN OF BELOW PACE VEHS, N=20	54.9	55.3	55.4	55.8	56.1	55.4	55.4	53.5
	100.0	100.7	100.9	101.6	102.2	100.9	100.9	97.4

MEAN SPEED, MPH
% OF ENTRY SPEED

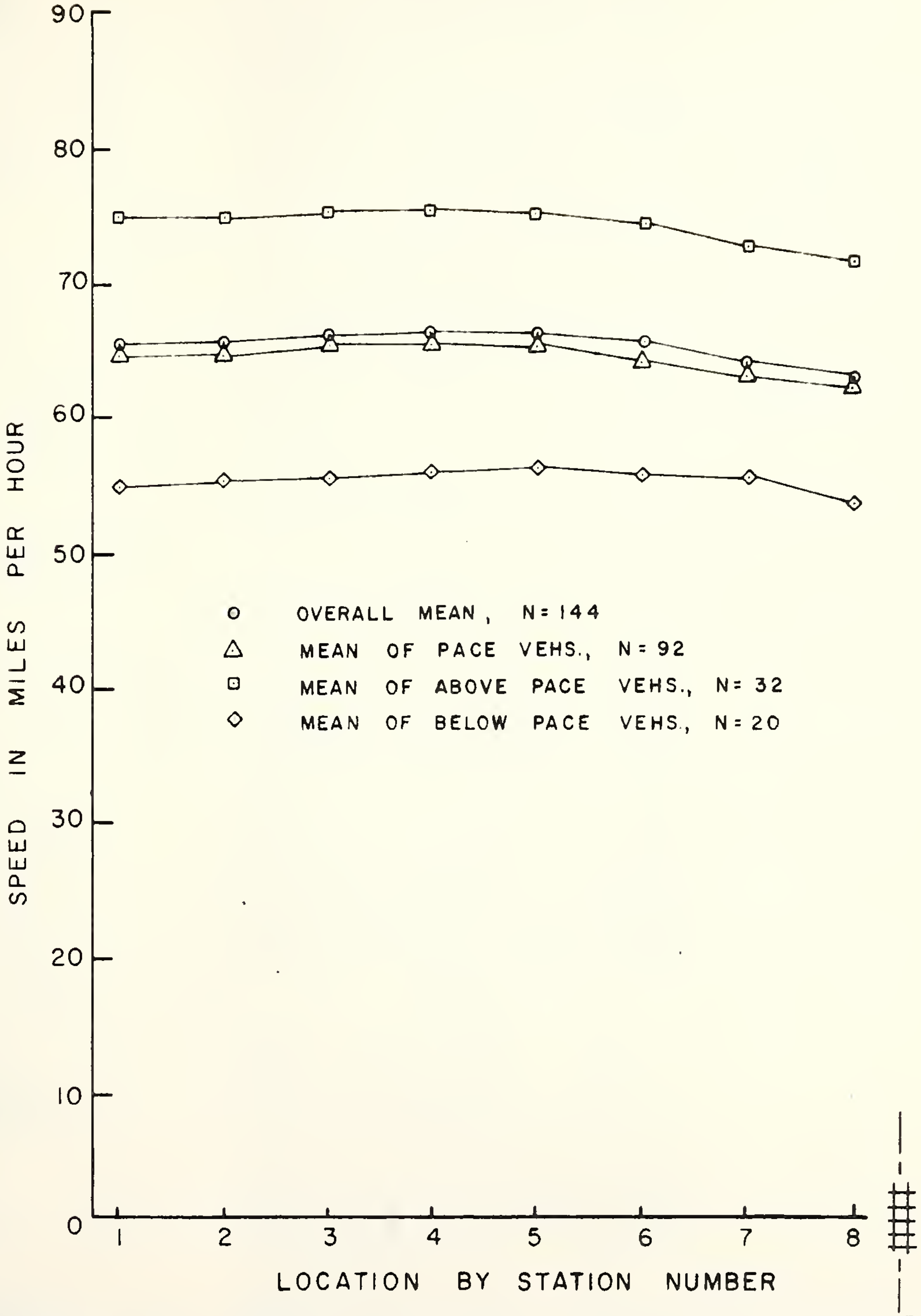


FIGURE 17. SPEED LOCATION GRAPH FOR NORTHBOUND FREE FLOW CARS

TABLE 10. SPEED LOCATION AND PER CENT OF ENTRY SPEED CHART FOR SOUTHBOUND FREE FLOW TRUCKS

	LOCATION BY STATION NUMBER							
	1	2	3	4	5	6	7	8
(OVERALL MEAN OF FREE FLOW CARS, N = 143)	(68.4	(68.3	(68.2	(68.6	(67.6	(67.1	(66.9	(66.3
	100.0)	100.0)	99.7)	100.3)	98.8)	98.1)	97.8)	96.9)
OVERALL MEAN OF FREE FLOW TRUCKS, N = 46	58.0	57.7	57.4	57.5	56.4	55.8	55.4	54.9
	100.0	99.5	99.0	99.1	97.2	96.2	95.5	94.6
MEAN OF PACE VEHS, N = 30 (PACE = 55–65, % = 68.2)	59.2	58.8	58.3	58.6	57.4	56.7	56.0	55.5
	100.0	99.3	98.5	99.0	97.0	95.8	94.6	93.7
MEAN OF ABOVE PACE VEHS, N = 5	69.0	69.0	69.2	69.2	68.8	67.6	68.6	68.2
	100.0	100.0	100.3	100.3	99.7	98.0	99.4	98.8
MEAN OF BELOW PACE VEHS, N = 11	49.8	49.6	49.1	49.4	48.2	47.8	47.5	47.3
	100.0	99.6	98.6	99.2	98.6	96.0	95.4	95.0

MEAN SPEED, MPH
% OF ENTRY SPEED

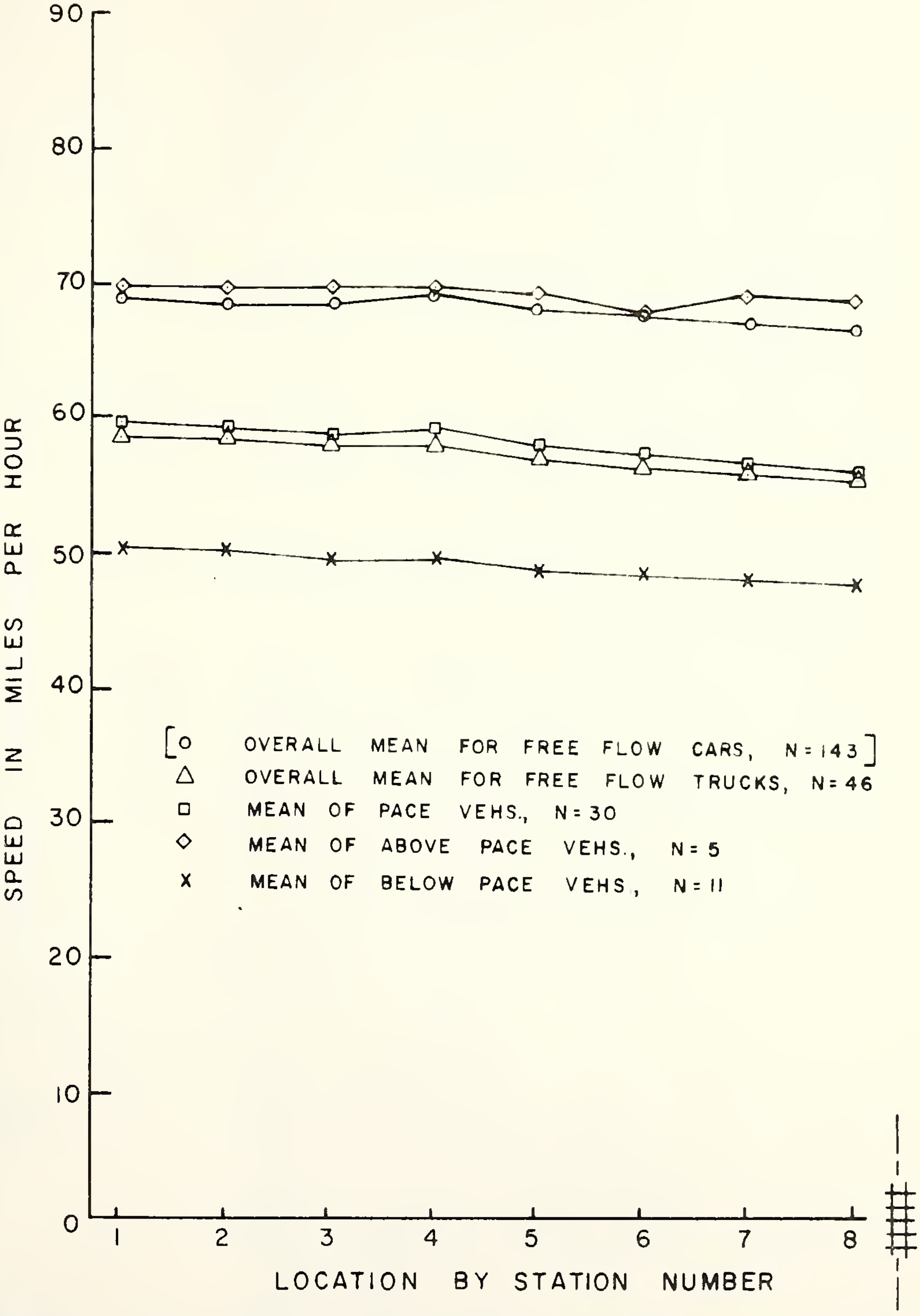


FIGURE 18. SPEED LOCATION GRAPH FOR SOUTHBOUND FREE FLOW TRUCKS

TABLE II. SPEED LOCATION AND PER CENT OF ENTRY SPEED CHART FOR NORTHBOUND FREE FLOW TRUCKS

	LOCATION BY STATION NUMBER							
	1	2	3	4	5	6	7	8
(OVERALL MEAN OF FREE FLOW CARS, N=144)	(64.7)	(64.7)	(65.3)	(65.2)	(65.2)	(64.3)	(62.9)	(61.9)
	(100.0)	(100.0)	(100.9)	(100.8)	(100.8)	(99.4)	(97.2)	(95.7)
OVERALL MEAN OF FREE FLOW TRUCKS, N= 79	53.4	53.4	54.0	54.1	54.1	53.7	52.5	51.4
	100.0	100.0	101.1	101.3	101.3	100.6	98.3	96.2
MEAN OF PACE VEHS, N=52 (PACE = 47–57, %=65.8)	52.0	52.1	52.7	52.9	53.1	52.6	51.6	50.7
	100.0	100.2	101.3	101.7	102.1	101.2	99.2	97.5
MEAN OF ABOVE PACE VEHS, N= 18	62.8	62.9	63.2	63.2	63.1	63.1	62.0	62.2
	100.0	100.2	100.6	100.6	100.5	100.5	98.7	99.0
MEAN OF BELOW PACE VEHS, N=9	42.1	42.2	42.6	42.6	42.3	41.1	38.1	33.8
	100.0	100.2	101.2	101.2	100.5	97.6	90.5	80.3

MEAN SPEED, MPH
% OF ENTRY SPEED

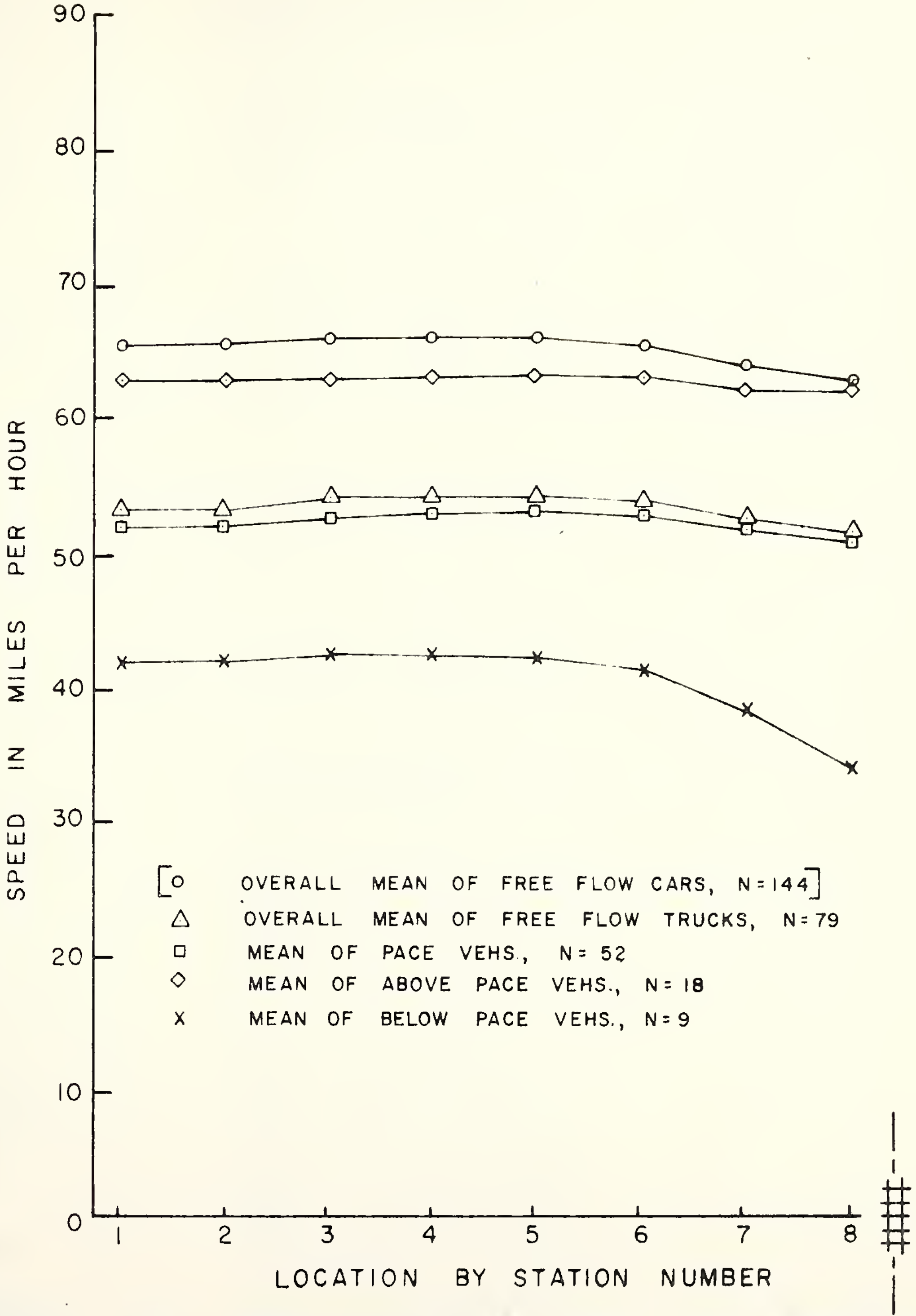


FIGURE 19. **SPEED LOCATION GRAPH FOR NORTHBOUND FREE FLOW TRUCKS**

TABLE 12. SPEED LOCATION AND PER CENT OF ENTRY SPEED CHART FOR ALL CLASSES OF SOUTHBOUND CARS

	LOCATION BY STATION NUMBER							
	1	2	3	4	5	6	7	8
OVERALL MEAN OF FREE FLOW VEHS, N=143	68.4	68.3	68.2	68.6	67.6	67.1	66.9	66.3
	100.0	100.0	99.7	100.3	98.8	98.1	97.8	96.9
OVERALL MEAN OF FIRST UNOBSTRUCTED VEHS, N=15	67.5	65.0	61.2	58.5	53.2	46.1	39.0	38.5
	100.0	96.3	90.7	86.7	78.8	68.3	57.8	57.0
OVERALL MEAN OF FIRST OBSTRUCTED VEHS, N=10	61.2	57.8	53.9	48.1	40.8	32.6	22.8	(0)
	100.0	94.4	88.1	78.6	66.7	53.3	37.7	(0)
OVERALL MEAN OF FOLLOWING VEHS, N = 33	47.9	44.6	40.8	36.8	30.9	23.4	13.9	(0)
	100.0	93.1	85.2	76.8	64.5	48.9	29.0	(0)

MEAN SPEED, MPH
% OF ENTRY SPEED

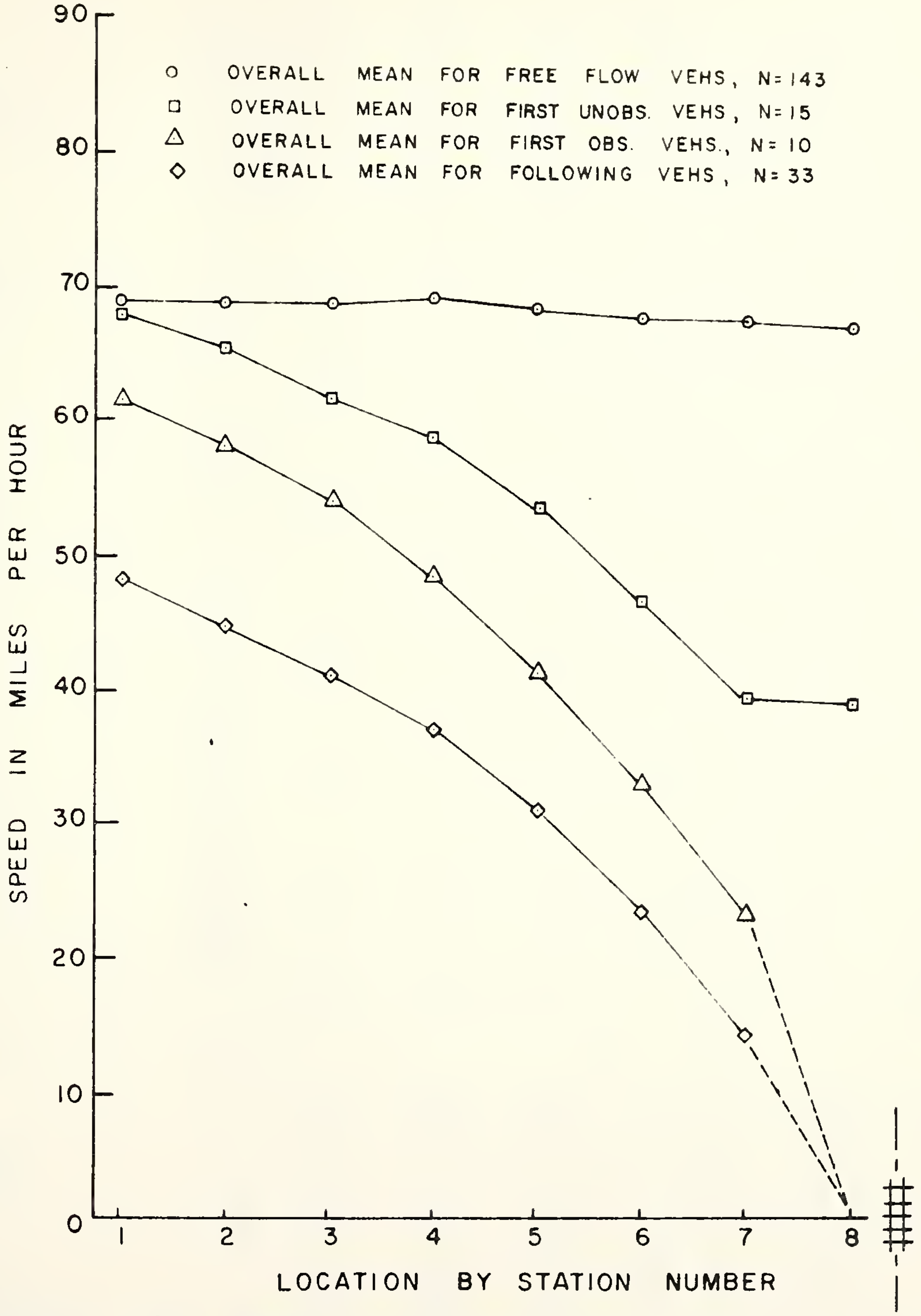


FIGURE 20. SPEED LOCATION GRAPH FOR ALL CLASSES OF SOUTHBOUND CARS

TABLE 13. TESTS ON DIFFERENCES BETWEEN MEAN ENTRY SPEEDS FOR ALL CATEGORIES OF SOUTHBOUND CARS ($\alpha = .05$)

VEHICLE CLASSIFICATION	n	MEAN ENTRY SPEED	STANDARD DEVIATION S	VARIANCE S^2	H_0. $\sigma_1^2 = \sigma_2^2$; H_1 $\sigma_1^2 \neq \sigma_2^2$			H_0 $\mu_1 = \mu_2$; H_1. $\mu_1 > \mu_2$		
					F_{CALC}	F_{CRIT}	RESULT	t_{CALC}	t_{CRIT}	RESULT
1-S.B. FREE FLOW CARS	143	68.4	6.3	39.7	1.786	1.92	DO NOT REJECT	0.533	1.657	DO NOT REJECT
2-S.B. FIRST UNOBS. CARS	15	67.5	8.4	70.6						
1-S.B. FREE FLOW CARS	143	68.4	6.3	39.7	3.540	2.16	REJECT	1.895	1.829	REJECT *
2-S.B. FIRST OBS. CARS	10	61.2	11.9	141.6						
1-S.B. FREE FLOW CARS	143	68.4	6.3	39.7	15.194	1.61	REJECT	12.038	1.691	REJECT *
2-S.B. FOLLOWING CARS	33	47.9	9.3	86.5						
1-S.B. FIRST UNOBS. CARS	15	67.5	8.4	70.6	1.982	3.23	DO NOT REJECT	1.544	1.714	DO NOT REJECT
2-S.B. FIRST OBS. CARS	10	61.2	11.9	141.6						
1-S.B. FIRST UNOBS. CARS	15	67.5	8.4	70.6	1.223	2.74	DO NOT REJECT	6.905	1.679	REJECT
2-S.B. FOLLOWING CARS	33	47.9	9.3	86.5						
1-S.B. FIRST OBS. CARS	10	61.2	11.9	141.6	1.621	2.55	DO NOT REJECT	3.688	1.683	REJECT
2-S.B. FOLLOWING CARS	33	47.9	9.3	86.5						

* t- TEST PERFORMED BY APPROXIMATE METHOD

vehicle with the slowest entry speed, and the vehicle exhibiting the most drastic deceleration. This information is offered in Tables 14 through 16 and Figures 21 through 23.

Following a similar sequence for all categories of northbound cars (Table 17 and Figure 24), tests were performed on the mean entry speeds for the four vehicle categories and are shown in Table 18. The results of these tests, differing slightly from the results for southbround cars, lead to the following conclusions: (1) free flow cars enter significantly faster than first obstructed and following cars, but at about the same speed as first unobstructed cars; (2) first unobstructed cars enter faster than both first obstructed and following cars; (3) the entry speeds for first obstructed and following cars are not distinguishable.

The spot speeds for each category of northbound cars are presented in Tables 19 through 21 and Figures 25 through 27. Once again, each category contains the overall average, the vehicles with fastest and slowest entry speeds, and the vehicle exhibiting the most drastic deceleration.

As previously mentioned, the 20 deceleration rates which were above the comfortable range were confined to only 13 vehicles. These vehicles are listed by vehicle category in Table 22. The entry speed for each vehicle is given along with the overall mean entry speed for that category. It can be seen that no abnormal deceleration rates were observed for free flow trucks or for following cars, but were divided between free flow cars, first unobstructed cars and first obstructed cars on each approach. In almost every

TABLE 14. SPEED LOCATION AND PER CENT OF ENTRY SPEED CHART FOR SOUTHBOUND FIRST UNOBSTRUCTED CARS WHICH DID NOT STOP AT THE CROSSING

	LOCATION BY STATION NUMBER							
	1	2	3	4	5	6	7	8
(OVERALL MEAN OF FREE FLOW VEHS, N=143)	(68.4)	(68.3)	(68.2)	(68.6)	(67.6)	(67.1)	(66.9)	(66.3)
	(100.0)	(100.0)	(99.7)	(100.3)	(98.8)	(98.1)	(97.8)	(96.9)
OVERALL MEAN OF FIRST UNOBSTRUCTED VEHS, N=15	67.5	65.0	61.2	58.5	53.2	46.1	39.0	38.5
	100.0	96.3	90.7	86.7	78.8	68.3	57.8	57.0
VEHICLE WITH FASTEST ENTRY SPEED	87.1	87.1	81.8	79.4	67.5	56.2	39.7	44.3
	100.0	100.0	93.9	91.2	77.5	64.5	45.6	50.9
VEHICLE WITH SLOWEST ENTRY SPEED	55.1	49.1	44.3	40.9	35.5	28.1	23.7	28.7
	100.0	89.1	80.4	74.2	64.4	51.0	43.0	52.1
VEHICLE EXHIBITING MOST DRASTIC DECELERATION	77.1	73.0	71.0	73.0	71.0	67.5	47.4	32.9
	100.0	94.7	92.1	94.7	92.1	87.5	61.5	42.7

MEAN SPEED, MPH

% OF ENTRY SPEED

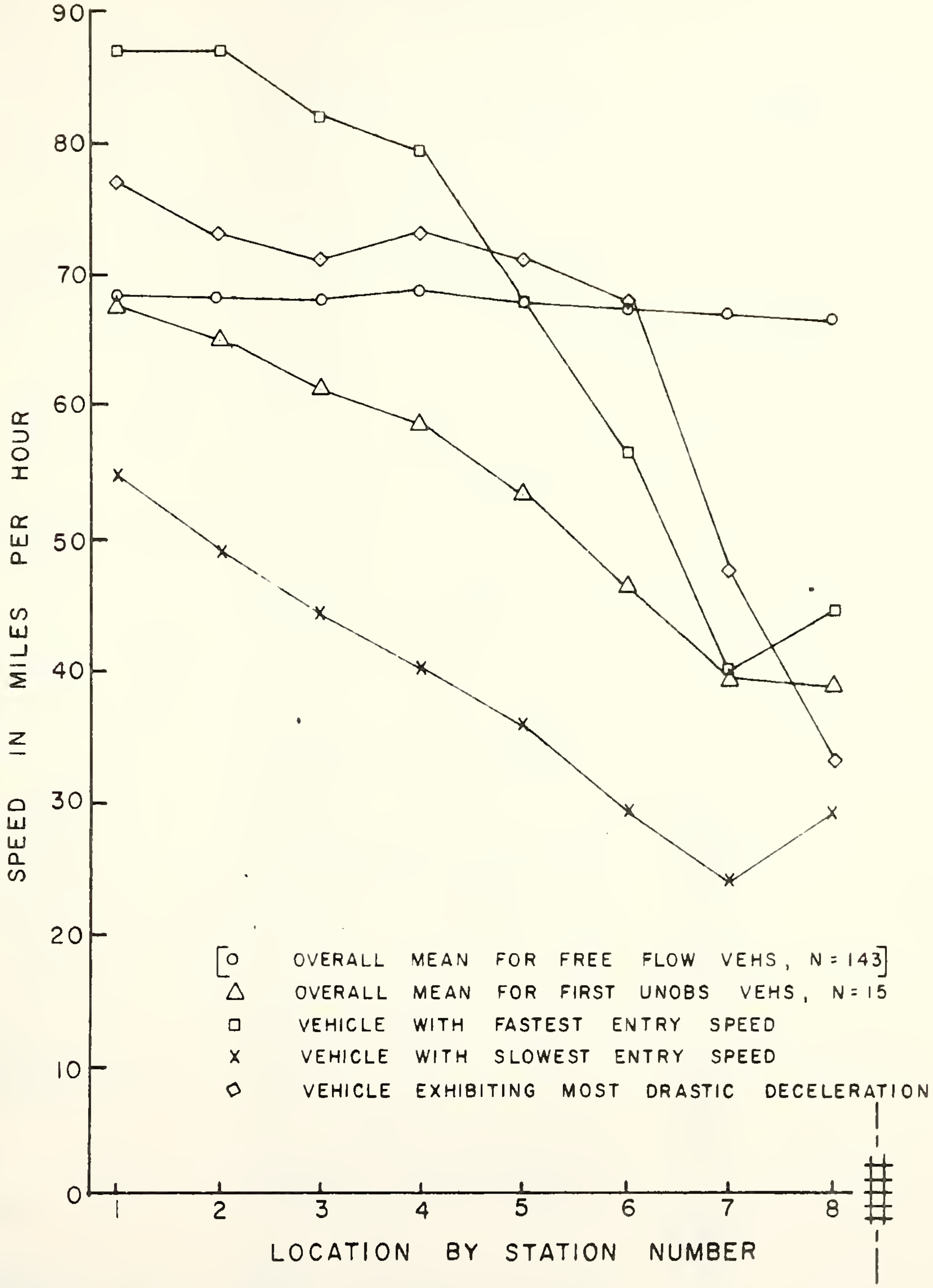


FIGURE 21. SPEED LOCATION GRAPH FOR SOUTHBOUND FIRST UNOBSTRUCTED CARS WHICH DID NOT STOP AT THE CROSSING

TABLE 15. SPEED LOCATION AND PER CENT OF ENTRY SPEED CHART FOR SOUTHBOUND FIRST OBSTRUCTED CARS

	LOCATION BY STATION NUMBER							
	1	2	3	4	5	6	7	8
(OVERALL MEAN OF FREE FLOW VEHS, N=143)	(68.4 100.0)	(68.3 100.0)	(68.2 99.7)	(68.6 100.3)	(67.6 98.8)	(67.1 98.1)	(66.9 97.8)	(66.3 96.9)
OVERALL MEAN OF FIRST OBSTRUCTED VEHS, N=10	61.2	57.8	53.9	48.1	40.8	32.6	22.8	(0)
	100.0	94.4	88.1	78.6	66.7	53.3	37.2	(0)
VEHICLE WITH FASTEST ENTRY SPEED *	79.4	77.1	73.0	64.3	50.0	39.1	31.0	(0)
	100.0	97.1	91.9	81.0	63.0	49.2	39.0	(0)
VEHICLE WITH SLOWEST ENTRY SPEED	45.8	42.9	39.7	38.6	35.5	31.8	25.7	(0)
	100.0	93.7	86.7	84.3	77.5	69.4	56.1	(0)

* THIS VEHICLE ALSO EXHIBITED THE MOST DRASTIC DECELERATION

MEAN SPEED, MPH
% OF ENTRY SPEED

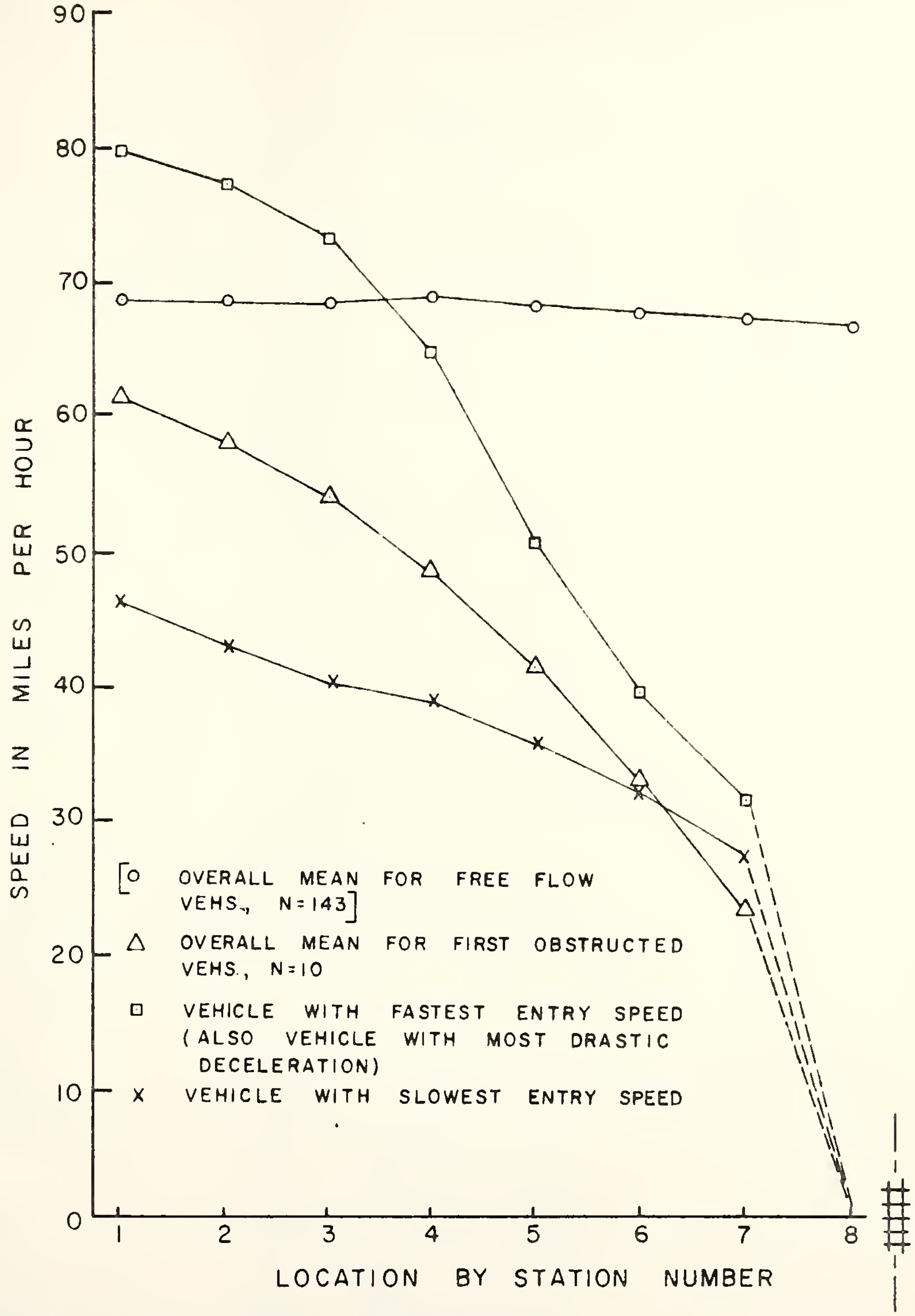


FIGURE 22. SPEED LOCATION GRAPH FOR SOUTHBOUND FIRST OBSTRUCTED CARS

TABLE 16. SPEED LOCATION AND PER CENT OF ENTRY SPEED CHART FOR SOUTHBOUND FOLLOWING CARS

	LOCATION BY STATION NUMBER							
	1	2	3	4	5	6	7	8
(OVERALL MEAN OF FREE FLOW VEHS, N=143)	(68.4 100.0)	(68.3 100.0)	(68.2 99.7)	(68.6 100.3)	(67.6 98.8)	(67.1 98.1)	(66.9 97.8)	(66.3 96.9)
OVERALL MEAN OF FOLLOWING VEHS, N=33	47.9	44.6	40.8	36.8	30.9	23.4	13.9	(0)
	100.0	93.1	85.2	76.8	64.5	48.9	29.0	(0)
VEHICLE WITH FASTEST ENTRY SPEED	67.5	61.3	51.9	39.1	29.0	25.7	20.9	(0)
	100.0	90.8	76.9	57.9	43.0	38.1	31.0	(0)
VEHICLE WITH SLOWEST ENTRY SPEED	28.1	28.1	28.4	27.5	25.7	25.0	(0)	(0)
	100.0	100.0	101.1	97.7	91.5	89.0	(0)	(0)

MEAN SPEED, MPH
% OF ENTRY SPEED

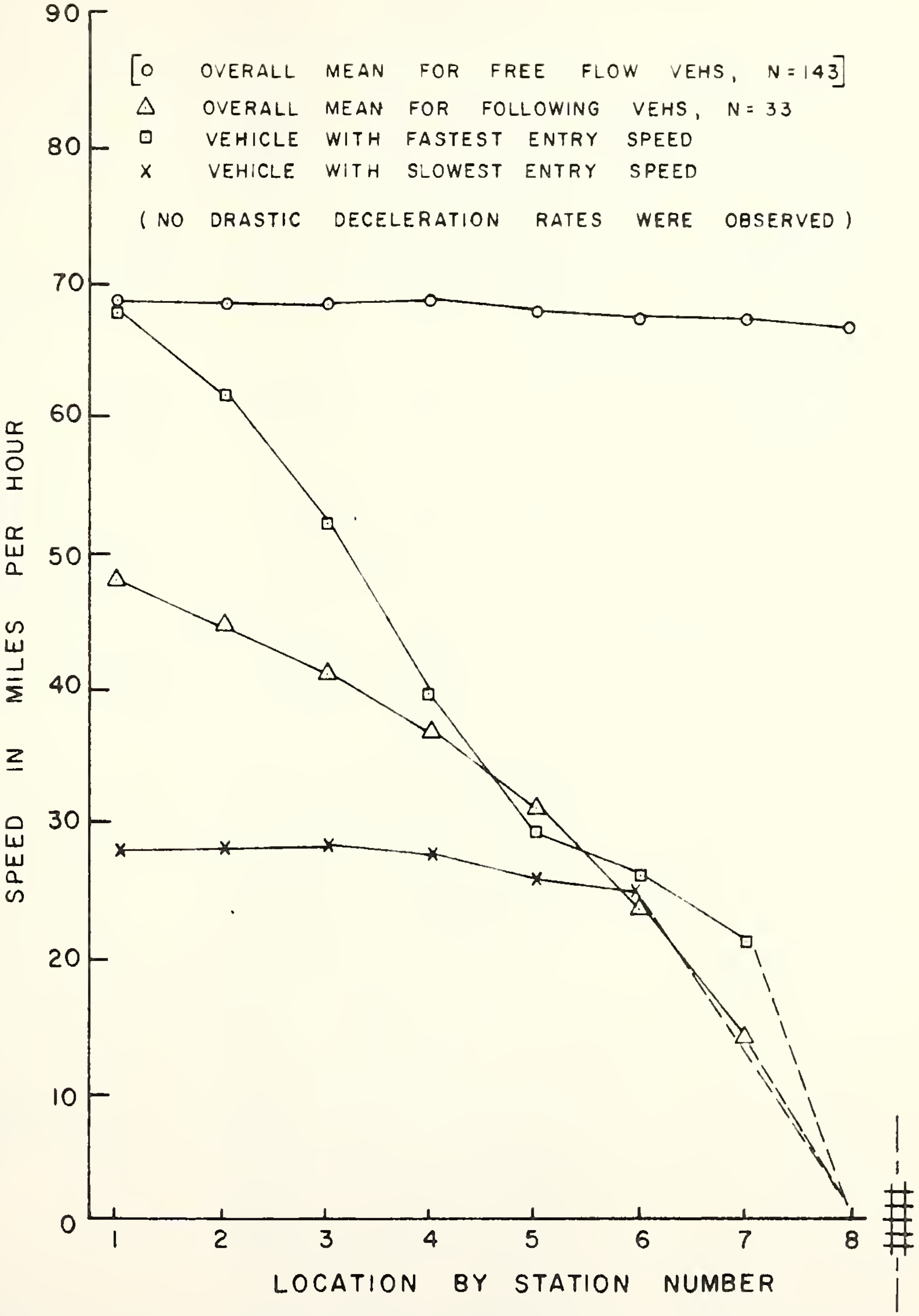


FIGURE 23. SPEED LOCATION GRAPH FOR SOUTHBOUND FOLLOWING CARS

TABLE 17. SPEED LOCATION AND PER CENT OF ENTRY SPEED CHART FOR ALL CLASSES OF NORTHBOUND CARS

	LOCATION BY STATION NUMBER							
	1	2	3	4	5	6	7	8
OVERALL MEAN OF FREE FLOW VEHS, N=144	65.6	65.7	66.2	66.1	66.1	65.4	63.9	62.8
	100.0	100.2	100.9	100.8	100.8	99.7	97.4	95.7
OVERALL MEAN OF FIRST UNOBSTRUCTED VEHS, N=15	64.7	63.4	61.1	57.5	52.7	45.7	36.9	27.1
	100.0	98.0	94.4	88.9	81.4	70.6	57.0	41.9
OVERALL MEAN OF FIRST OBSTRUCTED VEHS, N=10	50.2	48.7	45.8	41.3	36.2	29.2	20.1	(0)
	100.0	97.0	91.2	82.3	72.1	58.2	40.0	(0)
OVERALL MEAN OF FOLLOWING VEHS, N=25	47.3	45.2	43.1	40.6	36.2	30.6	18.7	(0)
	100.0	95.6	91.1	85.8	76.5	64.7	39.5	(0)

MEAN SPEED, MPH
% OF ENTRY SPEED

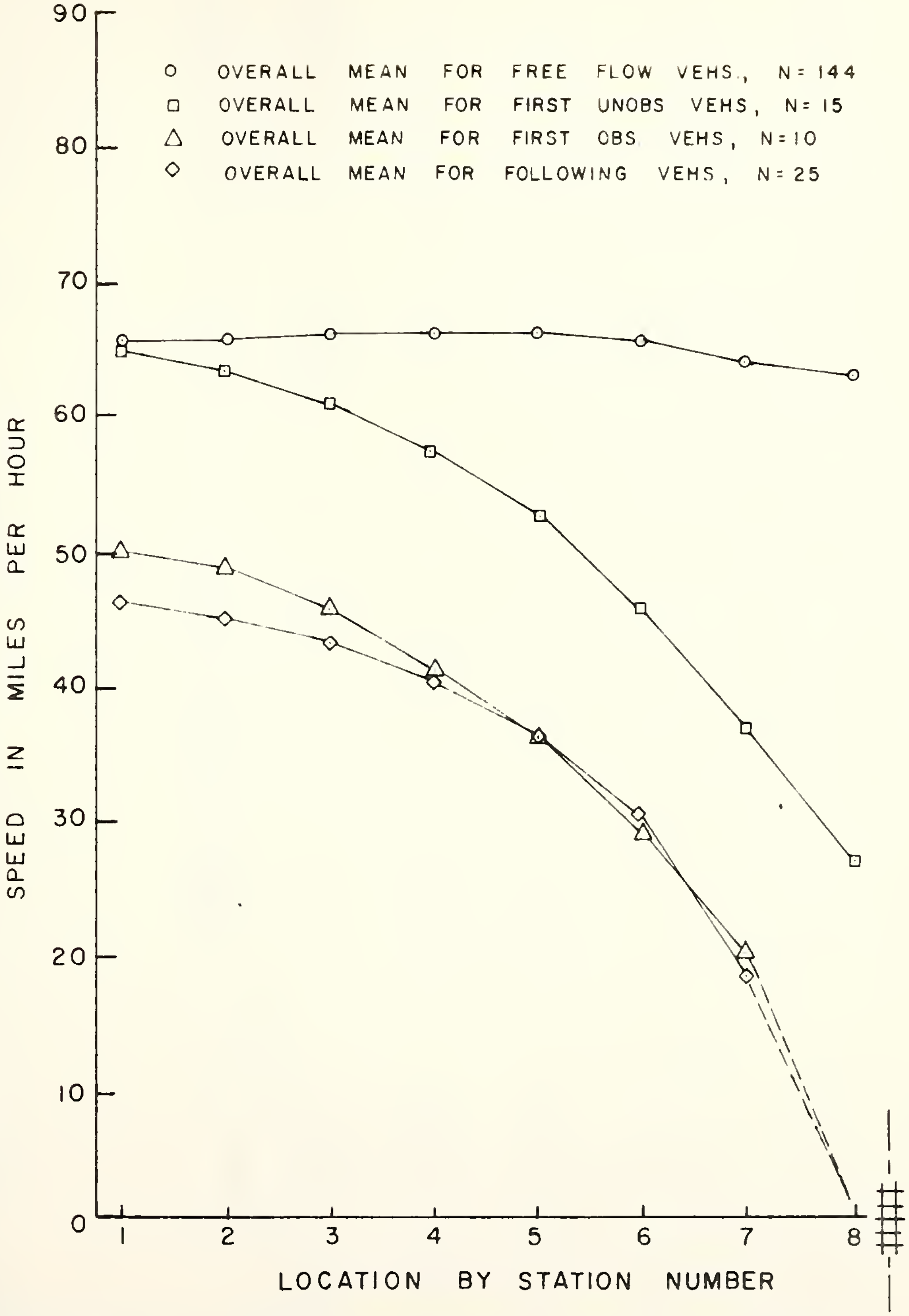


FIGURE 24. SPEED LOCATION GRAPH FOR ALL CLASSES OF NORTHBOUND CARS

TABLE 18. TESTS ON DIFFERENCES BETWEEN MEAN ENTRY SPEEDS FOR ALL CATEGORIES OF NORTHBOUND CARS ($\alpha = .05$)

VEHICLE CLASSIFICATION	n	MEAN ENTRY SPEED	STANDARD DEVIATION S	VARIANCE S^2	$H_0\ \sigma_1^2 = \sigma_2^2$; $H_1\ \sigma_1^2 \neq \sigma_2^2$			$H_0\ \mu_1 = \mu_2$; $H_1\ \mu_1 > \mu_2$		
					F_{CALC}	F_{CRIT}	RESULT	t_{CALC}	t_{CRIT}	RESULT
1-N.B. FREE FLOW CARS	144	65.6	6.9	47.6	1.351	1.92	DO NOT REJECT	0.467	1.657	DO NOT REJECT
2-N.B. FIRST UNOBS. CARS	15	64.7	8.1	65.6						
1-N.B. FREE FLOW CARS	144	65.6	6.9	47.6	5.320	2.16	REJECT	3.024	1.832	REJECT *
2-N.B. FIRST OBS. CARS	10	50.2	16.0	256.0						
1-N.B. FREE FLOW CARS	144	65.6	6.9	47.6	2.059	1.70	REJECT	8.875	1.715	REJECT *
2-N.B. FOLLOWING CARS	25	47.3	9.9	98.0						
1-N.B. FIRST UNOBS. CARS	15	64.7	8.1	65.6	3.939	2.23	REJECT	2.648	1.822	REJECT *
2-N.B. FIRST OBS. CARS	10	50.2	16.0	256.0						
1-N.B. FIRST UNOBS. CARS	15	64.7	8.1	65.6	1.525	2.91	DO NOT REJECT	5.735	1.687	REJECT
2-N.B. FOLLOWING CARS	25	47.3	9.9	98.0						
1-N.B. FIRST OBS. CARS	10	50.2	16.0	256.0	2.584	2.70	DO NOT REJECT	0.647	1.693	DO NOT REJECT
2-N.B. FOLLOWING CARS	25	47.3	9.9	98.0						

* t- TEST PERFORMED BY APPROXIMATE METHOD

TABLE 19. SPEED LOCATION AND PER CENT OF ENTRY SPEED CHART FOR NORTHBOUND FIRST UNOBSTRUCTED CARS WHICH DID NOT STOP AT THE CROSSING

	LOCATION BY STATION NUMBER							
	1	2	3	4	5	6	7	8
(OVERALL MEAN OF FREE FLOW VEHS, N=144)	(65.6)	(65.7)	(66.2)	(66.1)	(66.1)	(65.4)	(63.9)	(62.8)
	(100.0)	(100.2)	(100.9)	(100.8)	(100.8)	(99.7)	(97.4)	(95.7)
OVERALL MEAN OF FIRST UNOBSTRUCTED VEHS, N=15	64.7	63.4	61.1	57.5	52.7	45.7	36.9	27.1
	100.0	98.0	94.4	88.9	81.4	70.6	57.0	41.9
VEHICLE WITH FASTEST ENTRY SPEED*	75.0	73.0	69.2	73.0	64.3	51.9	37.5	18.7
	100.0	97.3	92.3	97.3	85.7	69.2	50.0	24.9
VEHICLE WITH SLOWEST ENTRY SPEED	47.4	47.4	48.2	45.8	42.9	39.1	29.0	32.1
	100.0	100.0	101.7	96.6	90.5	82.5	61.2	67.7

* THIS VEHICLE ALSO EXHIBITED THE MOST DRASTIC DECELERATION

MEAN SPEED, MPH
% OF ENTRY SPEED

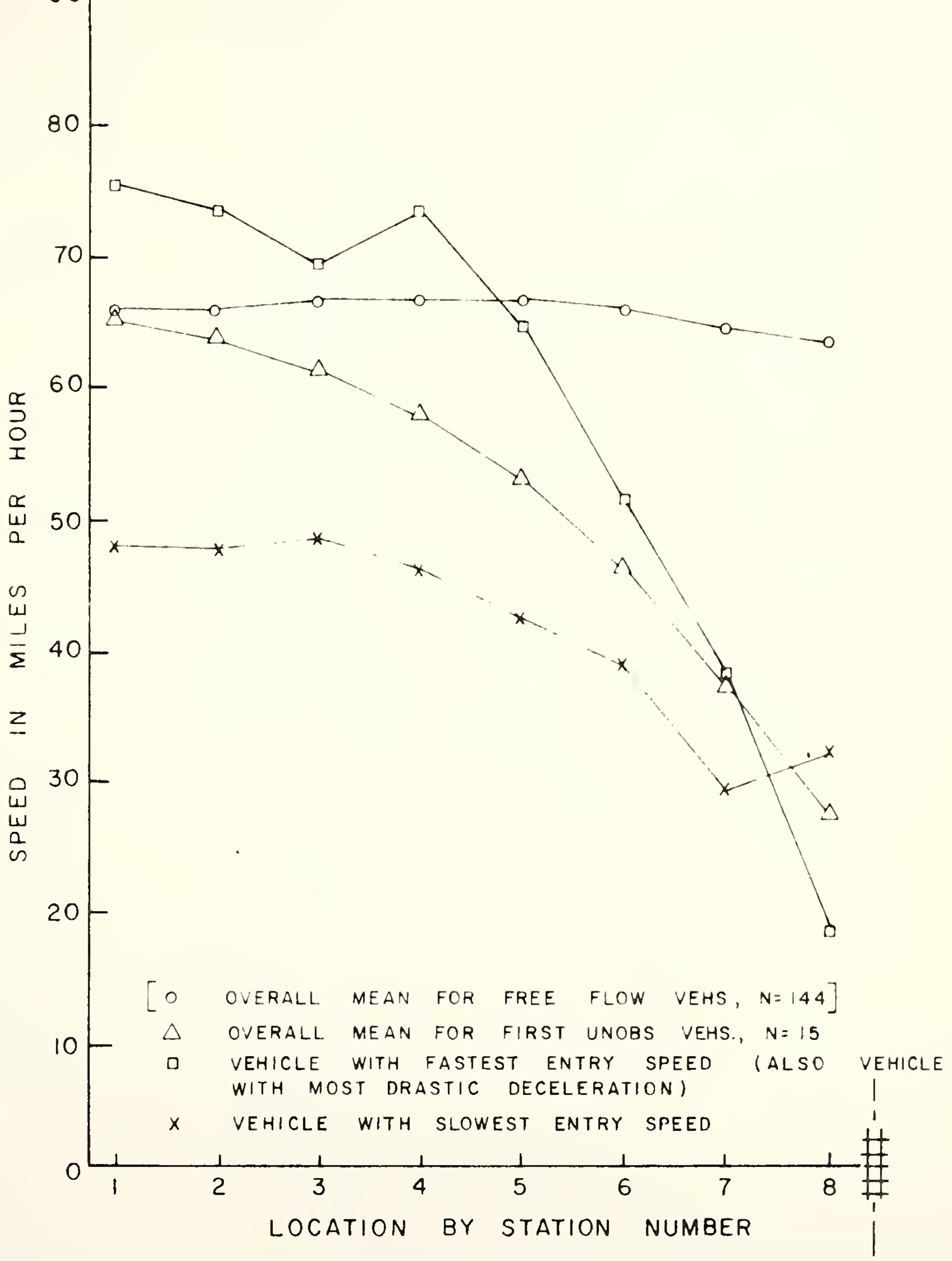


FIGURE 25. SPEED LOCATION GRAPH FOR NORTHBOUND FIRST UNOBSTRUCTED CARS WHICH DID NOT STOP AT THE CROSSING

TABLE 20. SPEED LOCATION AND PER CENT OF ENTRY SPEED CHART FOR NORTHBOUND FIRST OBSTRUCTED CARS

	LOCATION BY STATION NUMBER							
	1.	2	3	4	5	6	7	8
(OVERALL MEAN OF FREE FLOW VEHS, N=144)	(65.6 100.0)	(65.7 100.2)	(66.2 100.9)	(66.1 100.8)	(66.1 100.8)	(65.4 99.7)	(63.9 97.4)	(62.8 95.7)
OVERALL MEAN OF FIRST OBSTRUCTED VEHS, N=10	50.2 100.0	48.7 97.0	45.8 91.2	41.3 82.3	36.2 72.1	29.2 58.2	20.1 40.0	(0) (0)
VEHICLE WITH FASTEST ENTRY SPEED*	81.8 100.0	81.8 100.0	79.4 97.1	71.0 86.8	62.8 76.8	52.9 64.7	35.1 42.9	(0) (0)
VEHICLE WITH SLOWEST ENTRY SPEED	29.0 100.0	26.5 91.4	23.9 82.4	21.9 75.5	15.2 52.4	(0) (0)	(0) (0)	(0) (0)

* THIS VEHICLE ALSO EXHIBITED THE MOST DRASTIC DECELERATION

MEAN SPEED, MPH
% OF ENTRY SPEED

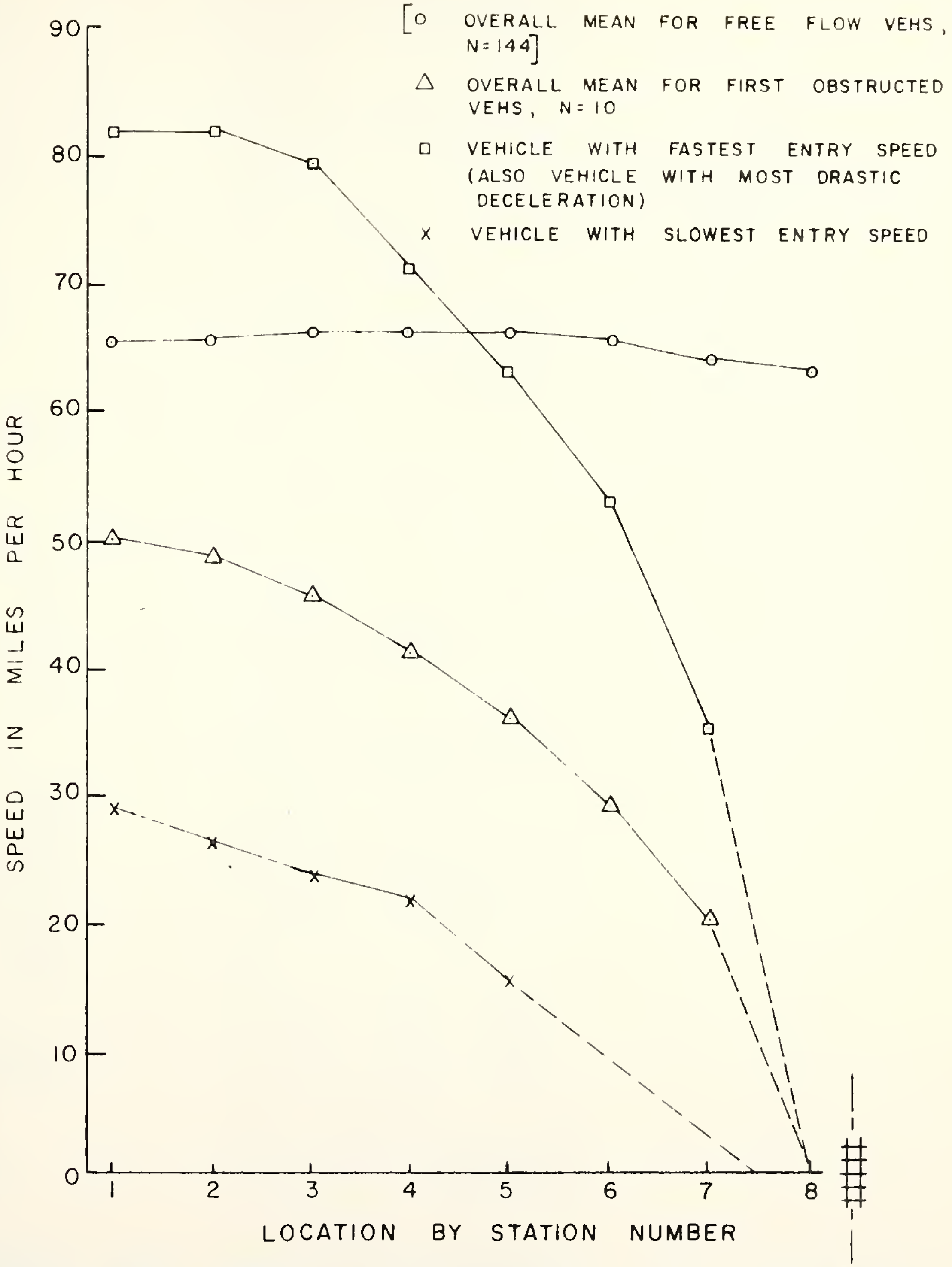


FIGURE **26.** **SPEED LOCATION GRAPH FOR NORTHBOUND FIRST OBSTRUCTED CARS**

TABLE 21. SPEED LOCATION AND PER CENT OF ENTRY SPEED CHART FOR NORTHBOUND FOLLOWING CARS

	LOCATION BY STATION NUMBER							
	1	2	3	4	5	6	7	8
(OVERALL MEAN OF FREE FLOW VEHS, N=144)	(65.6	(65.7	(66.2	(66.1	(66.1	(65.4	(63.9	(62.8
	100.0)	100.2)	100.9)	100.8)	100.8)	99.7)	97.4)	95.7)
OVERALL MEAN OF FOLLOWING VEHS, N=25	47.3	45.2	43.1	40.6	36.2	30.6	18.7	(0)
	100.0	95.6	91.1	85.8	76.5	64.7	39.5	(0)
VEHICLE WITH FASTEST ENTRY SPEED	69.2	67.5	60.0	52.9	44.3	33.3	17.3	(0)
	100.0	97.5	86.7	76.4	64.0	48.1	25.0	(0)
VEHICLE WITH SLOWEST ENTRY SPEED	25.0	20.4	19.6	19.1	19.6	21.4	(0)	(0)
	100.0	81.6	78.4	76.4	78.4	85.6	(0)	(0)

MEAN SPEED, MPH
% OF ENTRY SPEED

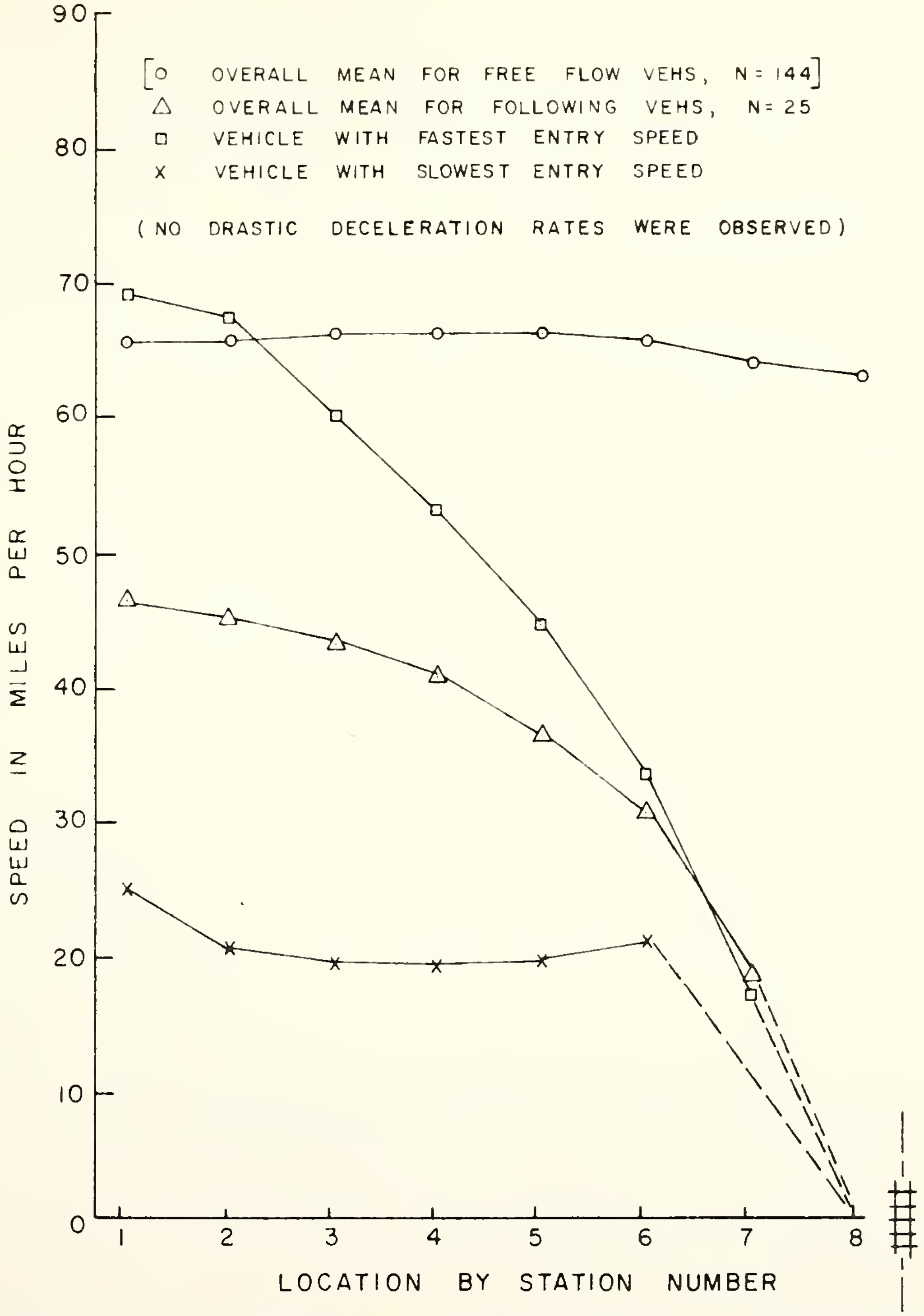


FIGURE 27. SPEED LOCATION GRAPH FOR NORTHBOUND FOLLOWING CARS

Table 22. Summary of Vehicles Exhibiting Deceleration Rate Higher Than the Comfortable Range.

Vehicle Category	Overall Mean Entry Speed	Vehicle Entry Speed	Class of Deceleration Rate Between Stations						
			1 & 2	2 & 3	3 & 4	4 & 5	5 & 6	6 & 7	7 & 8
S.B. FF Trucks									
None									
N.B. FF Trucks									
None									
S.B. FF Cars									
Veh. 1	68.4	81.8	1	1	1	1	2	1	1
N.B. FF Cars									
Veh. 1	65.6	73.0	1	1	1	1	1	2	1
Veh. 2		75.0	1	1	1	1	1	2	1
Veh. 3		90.0	2	1	1	1	1	1	1
S.B. 1st Unobs. Cars									
Veh. 1	67.5	67.5	1	1	1	1	2	1	1
Veh. 2		87.1	1	1	1	3	2	2	1
Veh. 3		77.1	1	1	1	1	1	4	2
N.B. 1st Unobs. Cars									
Veh. 1	64.7	75.0	1	1	1	2	2	2	1
Veh. 2		60.0	1	1	1	1	1	2	1
Veh. 3		69.2	1	1	1	1	2	1	1
S.B. 1st Obs. Cars									
Veh. 1	61.2	73.0	1	1	1	2	1	1	1
Veh. 2		79.4	1	1	2	3	1	1	1
N.B. 1st Obs. Cars									
Veh. 1	50.3	81.8	1	1	2	1	1	2	1
S.B. Following Cars									
None									
N.B. Following Cars									
None									

case, the vehicle entered the approach at a considerably higher rate of speed than the average for that category. It can also be seen that the higher than normal rates of deceleration occurred primarily in the portion of the approach between about 700 and 230 feet from the crossing. It is probable that the high rates of deceleration displayed by some of the drivers were due to their very high approach speeds. It is possible, however, that some of the high rates resulted because the driver of a vehicle did not become aware of the presence of the grade crossing or of an approaching train until such time that he was already fairly close to the crossing.

Four of the 13 vehicles exhibiting greater than comfortable deceleration were free flow cars. Three of these slowed quickly within about 500 feet of the crossing, a possible indication that these drivers were not aware of the crossing before that point. Another six of the vehicles were first unobstructed cars, all of which decelerated at high rates between approximately 700 and 230 feet from the crossing. It may be that these drivers did not see the activated flashing light signals early enough to slow comfortably. It is also possible that they did see the signals earlier, but at that point in the approach were still undecided as to whether or not they should try to beat the train.

The remaining three vehicles were first obstucted cars. Their excessive deceleration generally occurred earlier in the approach than for the previous categories, but there is

still indication that they may not have become aware of the hazard early enough.

Whatever the reason for these 13 motorists decelerating more severely than should have been necessary, it is clear that they may be members of that group of drivers who came closest to being involved in a grade crossing accident at this site during this study. While the vast majority of motorists respond favorably to present devices, the few who do not may need to be supplied with more forceful information regarding the hazard and their responsibility at the grade crossing. A reduction in the number of drivers who decelerate severely in the vicinity of a crossing may be one indication of the effectiveness of an innovative grade crossing protection device.

Summary of Results

From these comparisons, several points concerning vehicle performance in the vicinity of the crossing stand out. The inability to make comparisons on the basis of deceleration rates lends support to the argument that driver variability is the greatest single contributor to grade crossing accidents. That is, since nearly all of the observed vehicles decelerated safely when the situation warranted, and yet there have been numerous and serious accidents at this location, it appears that the accidents must involve singularly inattentive or distracted motorists. The "average motorist" appears to perform well.

It has been shown that certain categories of vehicles entered the approach at Station 1 at significantly lower

speeds than did other categories. This indicates that drivers in these slower categories became aware of the hazard and took corrective action before entering the length of the approach where data were collected. In each case, the slower vehicles were in a category benefiting from an added stimulus at the crossing ahead. In general it may be said that standard flashing light signals, operating when a train is not in immediate presence, are not commanding enough to slow drivers until comparatively close to the crossing. These drivers are anticipating the possibility that they may be able to traverse safely ahead of the train or they do not see the indication of a hazard as early as motorists in the other categories where hazard is indicated. Motorists approaching when the train is already across the road (or close enough so as to reach the crossing first), slow down sooner and decelerate more gradually than those with only the flashing lights in evidence. Finally, motorists who are faced with the flashers, train, and vehicles stopped in the roadway begin their deceleration at a point even further from the crossing. This last finding may help to explain why the presence of a physical barrier across the roadway, in the form of automatic crossing gates with flashing lights mounted on them, provide by far the best standard grade crossing protection. Perhaps the real value of gates lies in the possible earlier visibility by motorists of an approaching hazard and the elimination of

that group of motorists who are not obstructed from passing through the crossing after the activation of the protective devices and who then make the decision to beat the train.

The 13 vehicles displaying excessive rates of deceleration were free flow cars, first unobstructed cars or first obstructed cars. The high rates of deceleration generally occurred between 700 and 230 feet from the crossing, indicating that the drivers of these vehicles may not have become aware of the crossing or of an approaching train until they were relatively close to the crossing. The reduction in the number of such drivers, by supplying them with more forceful information concerning the hazard at a crossing, may be one indication of the effectiveness of an innovative grade crossing protection device.

Summary

This chapter has described a project initiated to evaluate the worth of various active improvements to standard flashing light signals at a hazardous grade crossing in Indiana. The site of the research has been described in detail, as have been the development and operation of the data collection system utilized to collect the data necessary for this evaluation. The data collected for Phase I of the study have been presented and compared by several categories based on the varying conditions at the crossing. It is anticipated that this data will serve as a base for cmparison when similar data are collected after each of the improvements are eventually implemented.

CHAPTER IV. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following conclusions summarize the findings of this research into highway-railway grade crossing protection devices.

1. There is a definable need for innovative active protection devices at grade crossings. These devices should be substantially lower in cost than an upgrading of standard protection (e.g., from flashing light signals to automatic gates), and yet offer a comparable increase in protection for the motorist.
2. There should be adequate facilities available for the development and convenient testing of such devices, and when an innovative device proves to be effective, channels should be available to allow for more widespread implementation.
3. The Indiana Green Light Signal is one device which is inexpensive and reported to be effective on low hazard roads. It may warrant application at many more grade crossings having relatively low hazard if it is modified to be more visible and reliable.

4. The photographic data collection and reduction process developed as a part of this research was relatively inexpensive and quickly implemented, and was effective in determining speed profiles and rates of deceleration for vehicles approaching a highway-railway grade crossing. It should have further application for similar studies where terrain, sight distance and climatic conditions permit.
5. It appears that grade crossing accidents involve singular inattentive or distracted motorists, based upon the fact that the groups of drivers in the several categories studied could not be distinguished by differences in deceleration rates between the categories.
6. Motorists approaching the grade crossing in this research reacted differently depending upon the prevailing conditions at the crossing. Drivers who entered the approach when the signals were activated without a train immediately present did not begin slowing their vehicles until relatively close to the crossing. Motorists viewing the added stimulus of a train across the road, or close to the crossing, slowed their vehicles earlier and decelerated more gradually. Motorists approaching behind vehicles which were already stopped for a train entered even slower. Thus, each of these

added stimuli at the crossing carried with it a corresponding earlier deceleration by the affected motorists. This may help to explain why automatic crossing gates, which present a stimulus similar to that of a stopped vehicle, have been proven to be the most effective type of standard crossing protection device.

7. Only 20 of the 3640 vehicle deceleration rates calculated in this study were higher than the comfortable range. Thirteen vehicles combined to create these 20 high rates. These vehicles were from the categories of free flow cars, first unobstructed cars or first obstructed cars. The abnormal rates generally occurred between 700 and 230 feet from the crossing. It is probable that some of these excessive rates were caused by the very high approach speeds of the vehicles, but it is also possible that some of the drivers did not become aware of the existence of the crossing or of an approaching train soon enough to slow their vehicles more gradually. Whatever the cause of these late responses, it is evident that these 13 drivers may be members of that group of drivers who came closest to being involved in a grade crossing accident at this site during this study. A reduction in the number of such incidents, by providing

more forceful information concerning the hazard of a crossing, may be one indication of the effectiveness of an innovative grade crossing protection device.

Recommendations for Further Research

As logical extensions of this research, the following areas are suggested for further study.

1. Develop, install and analyze innovative protective devices for highway-railway grade crossings with the view toward reducing grade crossing accidents at relatively low cost.
2. Investigate inter-agency relations and identify those areas which need to be improved in order to allow this development and testing to be more easily undertaken. Also examine and suggest needed improvements in the channels through which proven devices may be implemented.
3. Complete the study described in Chapter III by collecting and analyzing data after each of the planned improvements are implemented. The final result would hopefully be an indication as to which, if any, of the improvements have a positive impact on drivers in the vicinity of the crossing.

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